AIRCREW IONIZING DOSES FROM NUCLEAR WEAPON BURSTS

THESIS

Fred E. Garcia II, 1st Lieutenant, USAF

AFIT/GNE/ENP/01M-02

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

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Wright-Patterson Air Force Base, Ohio

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THESIS

Presented to the Faculty of the Graduate School of Engineering and Management

of the Air Force Institute of Technology

Air University

Air Education and Training Command

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Degree of Master of Science in Nuclear Engineering

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Acknowledgments

I wish to thank my family for their support throughout my time here at AFIT. I thank my mother, for her patience with those many phone calls and endless love that I do not deserve. I thank my brother, for never ending adventures and companionship and my sister, for her high spirit and determination. I would like to thank my niece, whose sweetness always brings a smile to my face, my nephew, who is very smart and always makes me strive for the better, and my nephew, who is only 2 years old, but has a peace about himself that I can't describe but can only learn from.

Lastly I thank My Lord and Savior, Jesus Christ. I would not be here if it weren't for Him. I want to refer the reader to Psalm 91 in the bible. This Psalm kept me going when so many times I wanted to quit.

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Abstract

Total radioactive doses to aircrew members have been calculated in the past using different methods. The methodologies include smearing models, disk-tosser codes, and puff models. This study uses output data from the Hazard Prediction and Assessment Capability (HPAC) code as input into a FORTRAN program written by the author to calculate total dose to aircrew members through sky-shine and cabin ingestion.

A description of the input parameters and new project setup in the Nuclear Weapon (NWPN) module within HPAC is given. The various aspects of controlling the project and plotting the data are also described. This information is presented essentially as a user's guide to NWPN that is focused toward the baseline case of this study.

The basic theory behind nuclear bursts including discussion about particle distribution is given. The particle distributions that are used in HPAC are plotted using different lognormal parameters in order to find a best fit for the data. This information is included in order to better understand the science behind HPAC's particle size distributions.

Theory of sky-shine and cabin ingestion dose is presented and a methodology to calculate total dose to aircrew members based on HPAC output data is given. The approach taken in this study is to use FORTRAN, oriented toward operational use, to extract this total dose for various altitudes, times after burst, and for different mission durations.

Aircrew Ionizing Doses from Nuclear Weapon Bursts

Chapter I: Introduction

A. Motivation

The survivability of an aircrew that flies through a radioactive post nuclear burst environment has been of interest to various agencies throughout the years. USSTRATCOM/J534 has a requirement to analyze the effects associated with the above-mentioned scenario. The biggest concern, at the moment, is the functionality of the aircrew. Can the aircrew fly through this type of environment and return, unharmed, to base having completed the mission? This research will explore potential improvements to the existing methodology used to calculate dose to aircrews resulting from nuclear bursts and make recommendations as to the practicality of implementing these improvements.

B. Background

Different computer codes have been used in the past to model predictions of radioactive environments on the ground caused by nuclear detonations. WSEG-10 (Weapon System Evaluation Group-10), the AFIT (Air Force Institute of Technology) model, and DELFIC (DEfense Land Fallout Interpretative Code) are three such codes that have been used to provide this type of environment. Currently, USSTRATCOM uses HPAC (Hazard Prediction and Assessment Capability) in conjunction with PEARL (Persistent Environment Aircraft Response Model) as a modeling method to get route specific dose rates. HPAC provides the radioactive environment and PEARL provides a dust environment along with route specific dust accumulation. Using HPAC and PEARL

together allows the calculation of the total dose to an aircrew that flies through a radiation environment. USSTRATCOM assumes a direct correlation between dust and radiation for calculation of total dose. This direct correlation allows for realistically accurate results to the problem without the expense of complex modeling and transport methods and long computational run time.

There are basically three different types of transport codes that have been used over the years. WSEG-10 and the AFIT model are cloud-smearing models. These codes use Gaussian distribution functions to transport radioactive particles through space and time. DELFIC is a disktosser code that includes modules to compute cloud rise information and the diffusive transport of particles. This is done by subdividing the particles of the cloud into disks and tracking the disks as they fall, diffuse, and are blown through the atmosphere.

HPAC uses DELFIC to build the initial cloud then uses a different code, SCIPUFF (Second-order Closure Integrated PUFF), to transport the particles. SCIPUFF is a second-order closure integrated puff model, which is based on a collection of Gaussian puffs that each represent arbitrary three-dimensional, time-dependent concentration fields [Sykes: V]. SCIPUFF splits and merges these puffs, transporting the particles through the atmosphere.

The Defense Threat Reduction Agency (DTRA) developed HPAC as a forward deployable, counterproliferation and counterforce evaluation tool for weapons of mass destruction including nuclear, biological, and chemical variations. There are different source models within HPAC that handle different threat scenarios including nuclear

weapons, reactor accidents, strikes on biological facilities, etc. The Nuclear Weapon (NWPN) source model is of interest here.

HPAC Version 3.2.1 is the latest version (at the time of this research), released in June, 2000 and is currently only authorized to US Government agencies and their contractors or for non-commercial academic research. This version of HPAC will run on a low end personal computer or desktop computer running Windows 95, 98, or NT that has at least a Pentium 90 with 16 MB of RAM. This makes HPAC very portable. PEARL is a dust environment code developed for the Defense Special Weapons Agency, now DTRA, by SAIC. The current version is just now able to run with Windows NT. Previous versions required a SUN Sparq 20 system.

The output of an HPAC run includes a time, location, altitude, and multi-burst dependent dose rate environment with up to 100 latitude/longitude points (30,000 if a different startup option is used) at a given altitude with the dose rate density at each point in space. HPAC has the capability to model 1000 weapons in this fashion but it will not be necessary to use all 1000 weapons in this study. Figure 1 illustrates the HPAC process [DTRA, 2000: 10].

There are 4 ways that an aircrew can be exposed to radiation when flying through a post-burst environment. These are ground-shine, skin-shine, sky-shine, and cabin ingestion. Ground-shine is due to the activity that has settled on the ground and is negligible for aircraft that fly at least a few gamma mean free paths above the ground, due to attenuation by the air. Skin-shine is the radiation hazard due to nuclear cloud particles that get attached to the outer skin of the aircraft. Sky-shine is due to the radioactivity still suspended in the cloud. Cabin ingestion is exposure due to the

radioactive dust that has entered the cabin by way of the incoming air that pressurizes and cools the cabin.

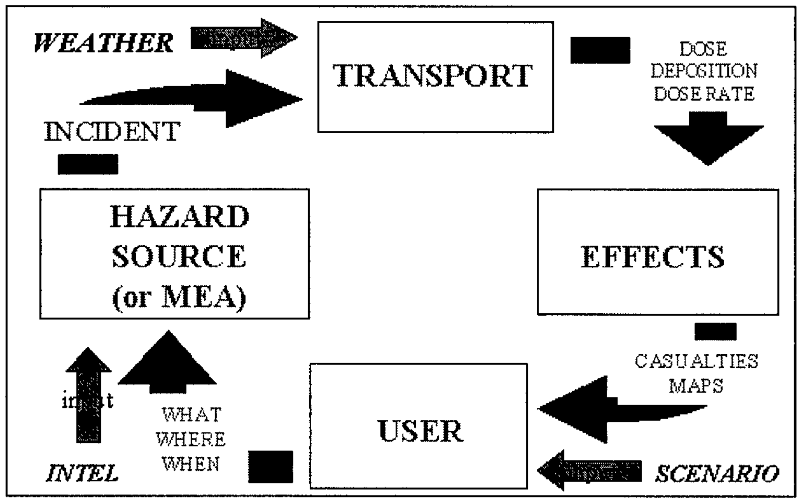

Figure 1: Basics of HPAC Operation

C. Problem

The primary objective of this research is to calculate the dose that an aircrew receives while flying through a radioactive cloud resulting from a nuclear burst using HPAC; more specifically to study HPAC output so that total dose, through sky-shine and cabin ingestion, that an aircrew receives, can be accurately calculated. Because of the complexity involved in using PEARL, it is desired to develop a method of calculating airborne doses using only HPAC. The FORTRAN program developed in this study will become the computational tool that USSTRATCOM could use to calculate total dose along a single aircraft route.

The baseline input case for HPAC will be a one-megaton surface burst with a fission fraction of 0.5 and zero winds. Previous students at AFIT have used this baseline case in smearing codes. This baseline case, used as input into HPAC, will allow for

comparison between the FORTRAN program mentioned above (using HPAC data output) and previous smearing code output.

HPAC takes user input, uses DELFIC, NewFall, or KDFOC3 (K-division DNA Fallout Code-3) to build the initial stabilized cloud, then uses SCIPUFF to transport the radioactive material through the atmosphere. Output data from HPAC will be studied and compared to work completed by previous AFIT students. This information will give insight as to the accuracy of using HPAC for this work.

D. Scope

The FORTRAN program, to be developed in this thesis, (which uses HPAC data output) will be used to get total dose to an aircrew that flies through a radioactive environment. Conners's thesis [Conners: 2] will be followed with the exception that this research will use SCIPUFF, a puff model, to transport the radioactive particles whereas Conners used the AFIT smearing model. The KC-135 and B-1B aircraft data that were used by Conners will also be used in this study so that a comparison of results can be made. This comparison will be useful because each study uses a different fallout transport code. The cloud model and dose analysis used by Conners will also be utilized to be congruent with the aircraft data that is used.

The focus of this thesis will be to use HPAC alone to generate the radiation environment and to implement a method to get route specific total dose to an aircrew without using PEARL. Also, only the NWPN source model is relevant for this research. The dose to the aircrew will be based solely on sky-shine and cabin ingestion. Ground shine will be neglected because of its insignificance to aircraft flying more than a few gamma mean free paths above the ground, ~ 130 m for 1MeV gamma rays at sea level.

Skin-shine will be considered beyond the scope of this research because of the complexity in calculating its value due to irregularities in the skin of an aircraft and because its contribution is speculated as being negligible [Bridgman: 431].

E. Assumptions

Several explicit assumptions are made in this study. They are:

1) The radiation from the radioactive cloud is isotropic meaning that the cloud, everywhere, is composed of the activity (or dose rate density) where the aircraft is at any point during its transit through the cloud.
2) The dose rate does not change significantly while the aircraft is traversing the cloud.
3) The aircraft does not penetrate the cloud prior to stabilization. Any aircraft that is near the cloud before stabilization is most likely going to be destroyed by prompt effects or by turbulence and debris in the rising fireball.
4) This study will assume 1 MeV gamma radiation throughout with a mass attenuation coefficient, $\left(\frac{\mu}{\rho}\right)_{air}$, of 0.0063015 m^2/kg to be congruent with Conners [Conners: 104].
5) All of the dust that enters the cabin remains there throughout mission duration and there is no internal shielding from the dust except by the air in the cabin.
6) The shielding factor for sky-shine (external) radiation can be found by using an "average" mass integral taken directly from the mass and surface area of the cabin and all of the cabin mass has the gamma-ray cross section of aluminum.
7) Doses are computed at the center of the aircraft cabin for simplicity. Doses at any other location in the cabin are very difficult to compute and are beyond the scope of this thesis.

F. Approach

A literature search was conducted to begin the research. Previous work on dose to aircrew conducted by Hickman, Kling, and Conners, previous AFIT students, was found. HPAC V3.2.1 was studied in order to obtain proficiency with the software package. Only the NWPN source model was used in this study since it is the only one of value with respect to dose to aircrew from a nuclear detonation.

Once the source code for the modules within HPAC was mastered and when the data output were studied, methods for calculating total dose to an aircrew began. Several data runs were conducted to find the dose to aircrew along specified aircraft routes.

G. Sequence of Events

Chapter II will present a description of Input in NWPN within HPAC. This chapter includes information on starting HPAC, setting up a new project, incident control parameters, and SCIPUFF execution with data plots and output files. Chapter III gives the background of radiation, particle distributions, and a description of the initial stabilized cloud. Plots of particle distributions that are used in HPAC are given as well as the DELFIC default distribution and a 100-group volumetric, equal activity distribution. Concerns about the particle distributions used in HPAC are discussed as well as transport of particles and vertical activity comparisons (smearing model and HPAC). Chapter IV describes the dose analysis background that is used in this study with Chapter V reporting this studies results. Appendices include a program that calculates a 100-group particle distribution, the NEWTRANS.OUT file used by HPAC in this study, sample HPAC

output data, the program that calculates results that are compared to Conners' results, and a program that calculates single route total dose to aircrew members.

Chapter II: Description of Input in NWPN within HPAC

A. Background

HPAC is a forward deployable, counterproliferation and counterforce tool for weapons of mass destruction (WMD). This program is intended to assist war fighters with assessment of war scenarios. HPAC is a forward deployable program because it can be run on personal computers. This research makes use of a Dell Inspiron 7000 laptop with a 366 Pentium II processor and 128 Mbytes of RAM. This chapter describes the input parameters of NWPN within HPAC.

There are 3 versions of HPAC: Operational, Extended, and Ultimate. Table 1 is a re-creation of the HPAC users guide Table 4.1 and just shows maximum parameter values that get used in each version of HPAC. This research uses Ultimate mode for all scenarios because this mode is most detailed, will give the most accurate results, and is well within the capabilities of the laptop used [DTRA, 1999: 31].

HPAC was designed for two types of users, operational users and analytical users. This gives rise to two different edit modes, Operational Edit Mode and Advanced Edit Mode. Operational Edit Mode allows user input of the basics of the scenario including What, Where, and When data without knowing all of the scientific details of the release. Advanced Edit Mode gives a user full control of the release parameters. A user can switch between the different edit modes and it is sometimes useful to do so. This option will be discussed in more detail later in this chapter.

Table 1: Maximum Parameter Values Used in Each Version of HPAC

Maximum	Standard	Extended	Ultimate
Incidents	10	100	100
Releases	25	1,000	8,000
Puffs	20,000	40,000	60,000

B. Starting HPAC

HPAC runs under Windows. Figure 2 shows the HPAC startup screen.

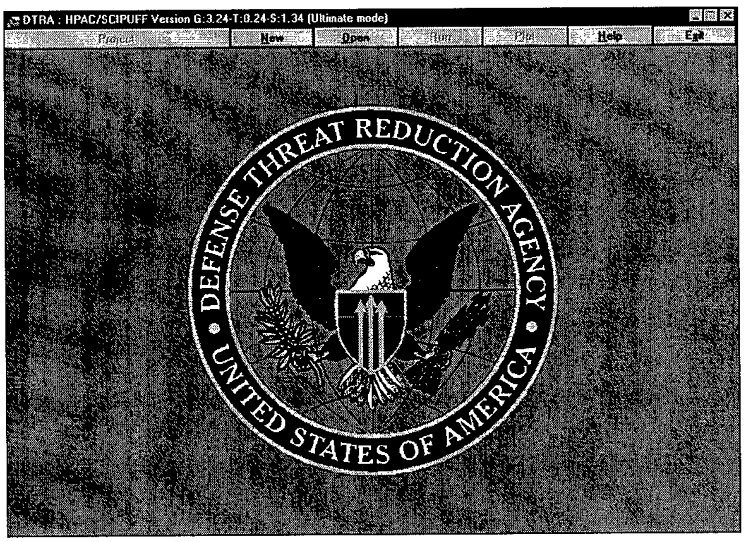

Figure 2: HPAC Startup Screen

Starting HPAC in the standard way will allow a maximum of 100 data points to be output in table format. Up to 30,000 data points can be used if the following startup options are used from the run command line in Windows: C:\hpac\bin\puscipuf.exe /S:N /T:30000, for the Ultimate version and C:\hpac\bin\pxscipuf.exe /S:N /T:30000 for the Extended Version. This will also be discussed in more detail later in this chapter. Either way the HPAC Startup Screen pops up. From the startup screen, a user can create a new project or open an existing one. The next section will explain the basics of creating a new project. Many menu options exist within HPAC, however only those pertinent to this exercise will be

discussed. More extensive software information can be found in the HPAC User's Guide [DTRA, 1999].

C. New Project Setup

When the "New" button is pressed in the startup screen, the "Save As File Control" window will pop up as shown by Figure 3. The new project is named here. Mytest#2 is used for this description.

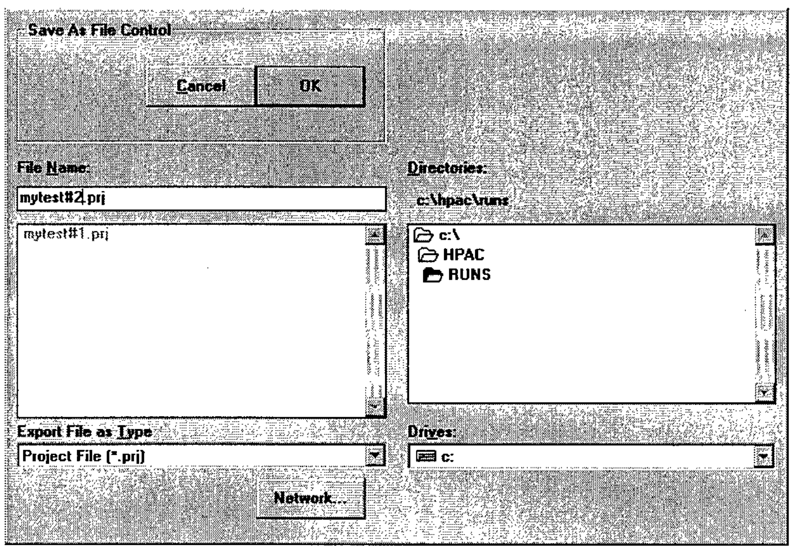

Figure 3: Save As File Control Window

Figure 4 shows the New Project Setup window. Most of the time it is best to accept the default values given. However, Fast Mode can be chosen here, if desired, in the Mode drop-down menu. Running HPAC in Fast Mode speeds up SCIPUFF run time considerably, but at the cost of accuracy. Selecting the "OK" button brings up Figure 5, the New Project Editor.

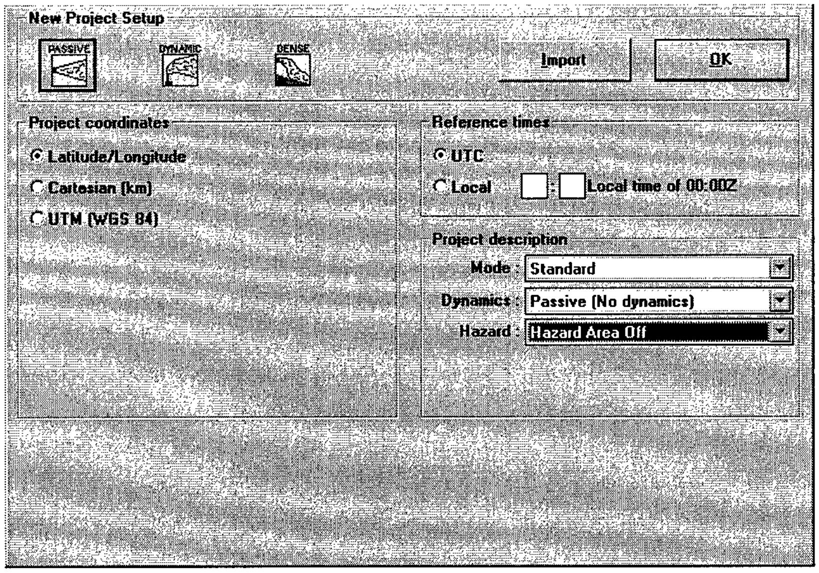

Figure 4: New Project Setup

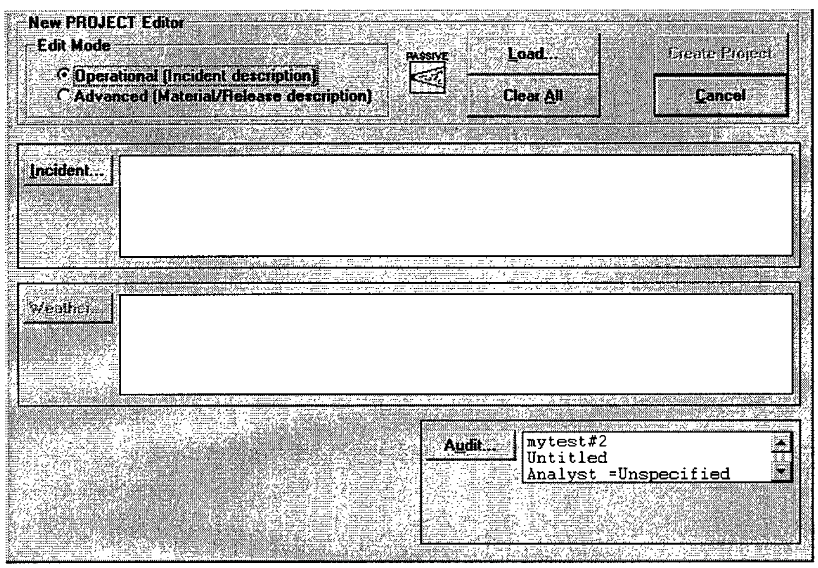

Figure 5: New Project Editor

The New Project Editor is where the Operational or Advanced Edit Mode can be chosen. The most user-friendly method of inputting data is to first use the Operational Edit Mode to set up the initial nuclear weapon incident as this provides all the initial values for the Advanced Edit Mode options. These options can be modified later if

desired. This is simpler than defining all of the advanced options at the outset. Clicking on the "Incident" button brings up Figure 6, the Incident Control window.

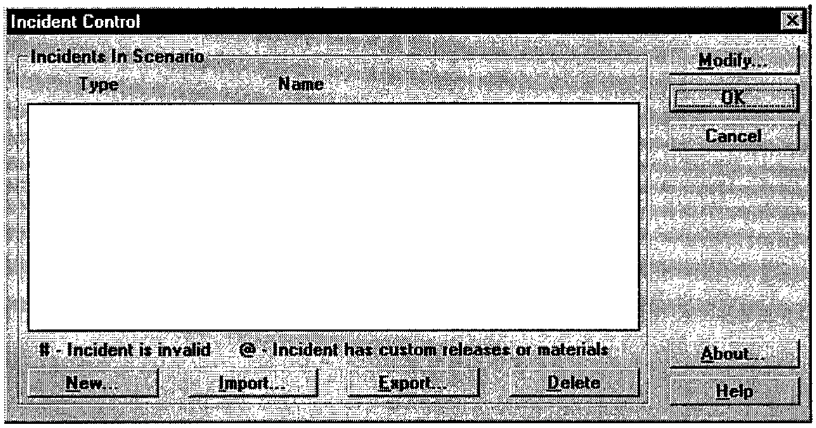

Figure 6: Incident Control

D. Incident Control

The Incident Control box will also come up if an existing project is opened (from Figure 2). Clicking the "Modify" button will let a user modify an existing project. For this new project, the "New" button needs to be clicked. This brings up Figure 7, the New Incident window.

This figure shows the different incident types that HPAC can handle. This is also where NWPN first gets chosen. NWPN is the Nuclear Weapon incident type. An incident name needs to be given to the project here and "My Nuclear Weapon" has been chosen for this description. Clicking on "Nuclear Weapon" in the Incident Type and then clicking on the "Continue" button will bring up Figure 8, the Nuclear Weapon Strike Dialog window. This window displays the When, Where, and What information (Operational Edit Mode).

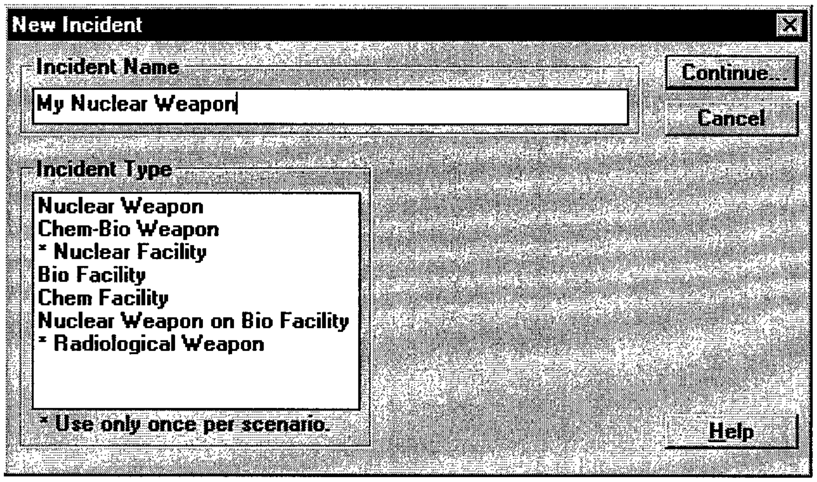

Figure 7: New Incident

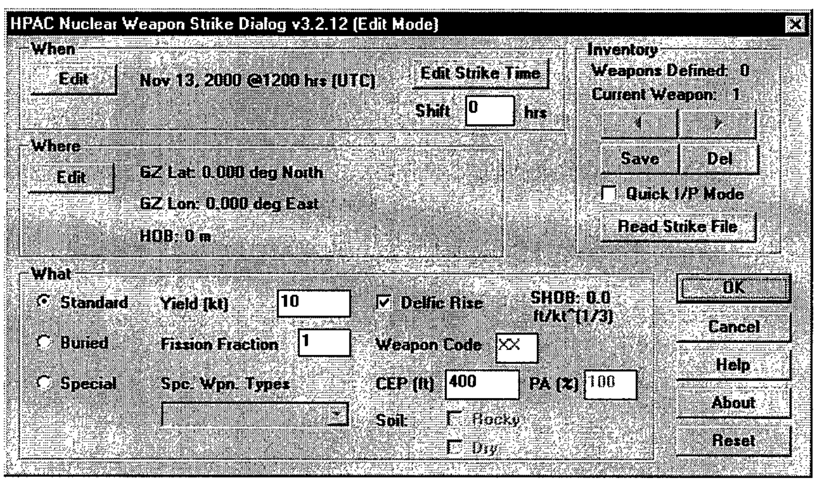

Figure 8: HPAC Nuclear Weapon Strike Dialog

The starting date and time is specified in the "When" edit window. The location of the incident is specified in the "Where" edit window, including Height of Burst (HOB). The "What" part of the Strike Dialog Window is where the yield of the weapon and fission fraction is specified. Also, this is where the DELFIC cloud rise option is selected if the Standard option is also selected. This option is for above ground bursts. If the DELFIC option is not selected, NewFall is used. If the Buried option is selected,

KDFOC3 is used. The "Special" option is for weapon types other than the default U238 material type weapon. The other options in the "What" part of the dialog box can be left as default. These are more for casualty estimates that HPAC can give. The "Inventory" part of the Strike Dialog Window is used when multiple bursts are needed. Strike files containing multiple weapon data can be created and used. For one weapon, the default settings should be used. Once all the desired options are selected and specified, The New Project Editor (Figure 5) comes back up with a red check mark underneath the "Incident" button.

The "Weather" option must be chosen next. Figure 9 shows the Weather Editor. There are many different weather options that can be set up here including surface moisture, surface type, and cloud cover. Also, if connected to the Internet, different weather servers can be accessed to pull in actual weather data. The setup found to be most useful for this research was to use the "Fixed Winds" option in the "Weather Data Type" pull down menu. Any wind speed that is desired can be used. Figure 10 shows the "Fixed Winds" option within the weather editor.

After the desired weather is selected, the New Project Editor (Figure 5) comes up again with a red check mark under the "Weather" button. Figure 11 shows the New Project Editor in Advanced Edit Mode along with each feature of the project that can be edited. It was mentioned earlier that a user could switch between Operational and Advanced Edit Mode. It is interesting to go back into Advanced Edit Mode after the incident is set up in Operational Edit Mode. This allows a user to see the exact details of each option that is used in NWPN.

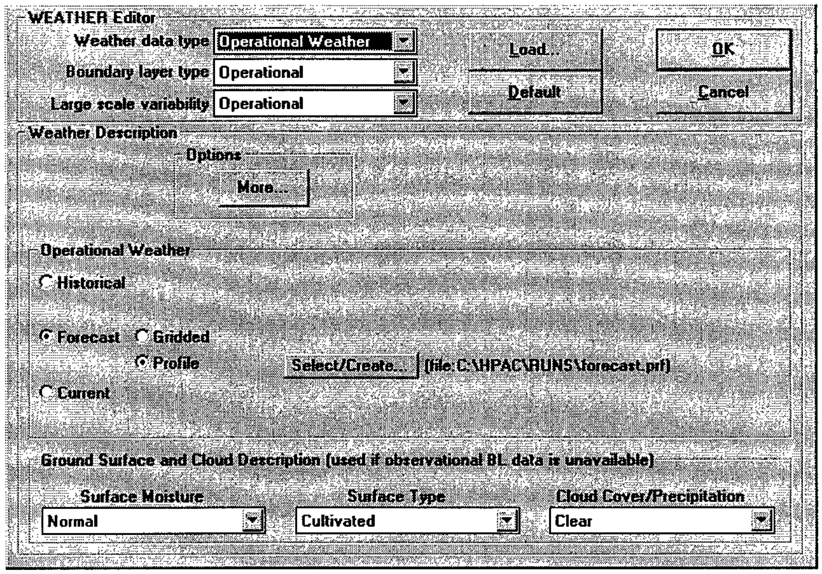

Figure 9: Weather Editor

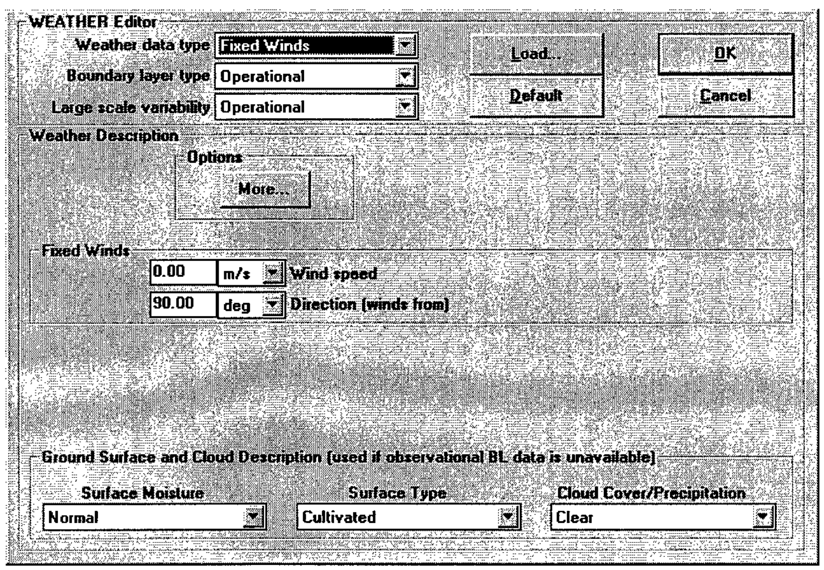

Figure 10: Weather Editor, Fixed Winds Option

The main reason to go into Advanced Edit Mode is to edit the data output intervals. Pressing the "Time" button takes the user into the "Time Editor" within the Advanced Edit Mode. Figure 12 shows this time editor with data output intervals of 30 minutes with a 10-hour project duration. This means that HPAC will only report data up to 10 hours after the burst. This, of course, can be changed if desired. It is important to

specify the data output intervals correctly for each project because these intervals will be the only intervals available for plotting. If, after SCIPUFF runs the intervals aren't correct, the project can be edited and the intervals corrected.

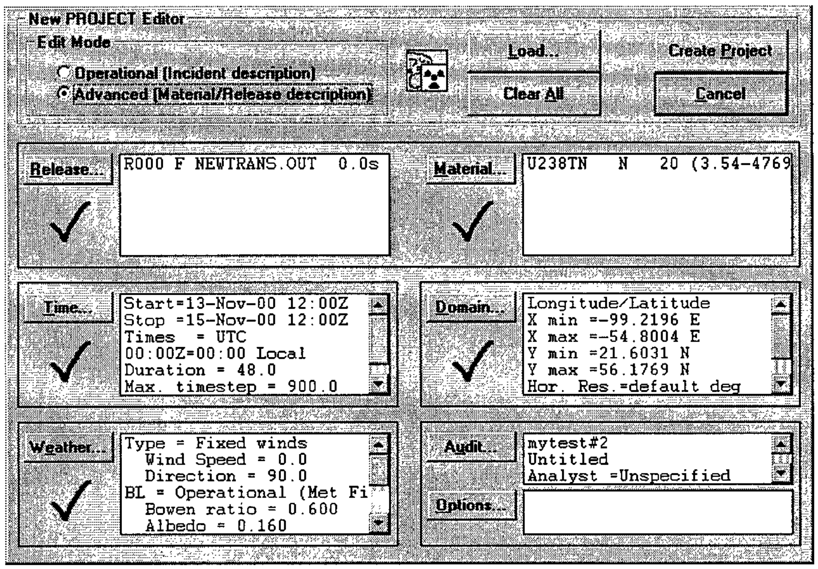

Figure 11: New Project Editor (Advanced Edit Mode)

Another interesting feature in the Advanced Edit Mode is the Material Editor shown in Figure 13. This window pulls in information about the material file that NWPN uses including density (if the "Properties" button is pressed), decay law parameter, and particle distribution. These different parameters can be edited if desired although it is not advised [DTRA, 1999: 163].

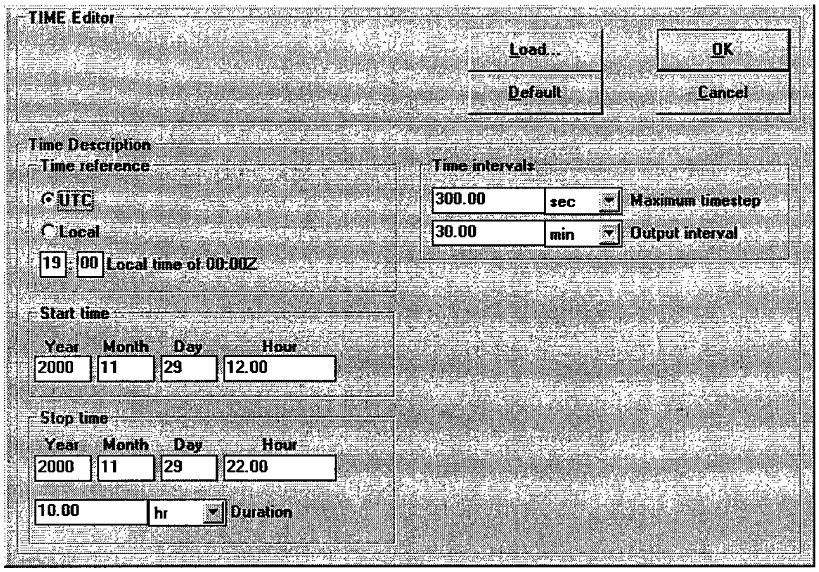

Figure 12: Time Editor Within Advanced Edit Mode

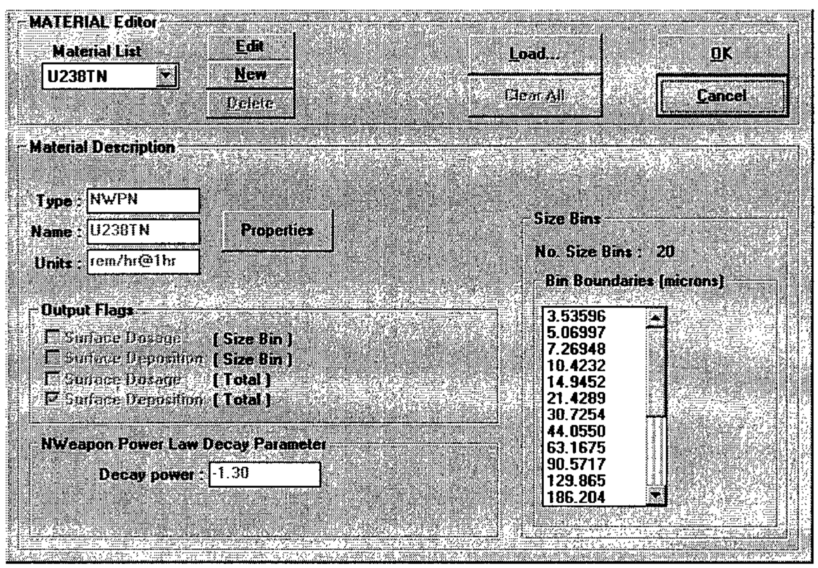

Figure 13: Material Editor

E. SCIPUFF Run and Data Plots with Output

Once the project is completely set up, the "Create Project" button can be clicked (shown in Figure 5 if in Operational Edit Mode or in Figure 11 if in Advanced Edit Mode). This will create the appropriate cloudtrans file (either NEWTRANS.OUT for

standard scenarios or KDTRANS.OUT for buried scenarios). The HPAC user's guide for this version of HPAC states that there is a Runtime View that displays the cloud to allow study of the cloud that will be transported [DTRA: 166], but this version of HPAC does not include a Runtime View. This is something that DTRA will need to update in the HPAC user's guide. After the cloudtrans file is built, which includes puff information, SCIPUFF takes over for transport of the particles. HPAC displays SCIPUFF run information while it computes necessary information for plot display.

After SCIPUFF finishes the transport, the Plot Control window is displayed, as shown in Figure 14. All of the plot options can be adjusted here to user specification. As shown in the figure, the "Horizontal Slice" plot choice is going to be most useful to this research. This horizontal slice is an instantaneous horizontal slice through the cloud giving dose rate density data at a user-specified altitude and time. The units of the data are in $\frac{rem}{hr \bullet m^3}$ @1-hr and are shown in the figure.

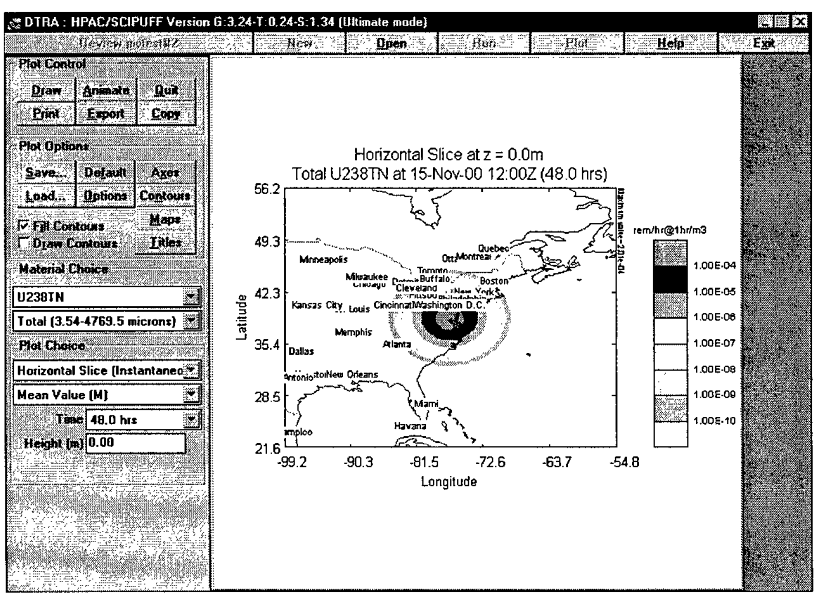

Figure 14: Plot Control

The plots can be altered to look pretty much any way a user desires including changing the contours of the data, the style of the contours, the axes styles including coordinate units, title of the plot, and other plot parameters.

In order to export the data displayed in the plot, the "Export" button needs to be clicked. Figure 15 shows the Save As File Control window.

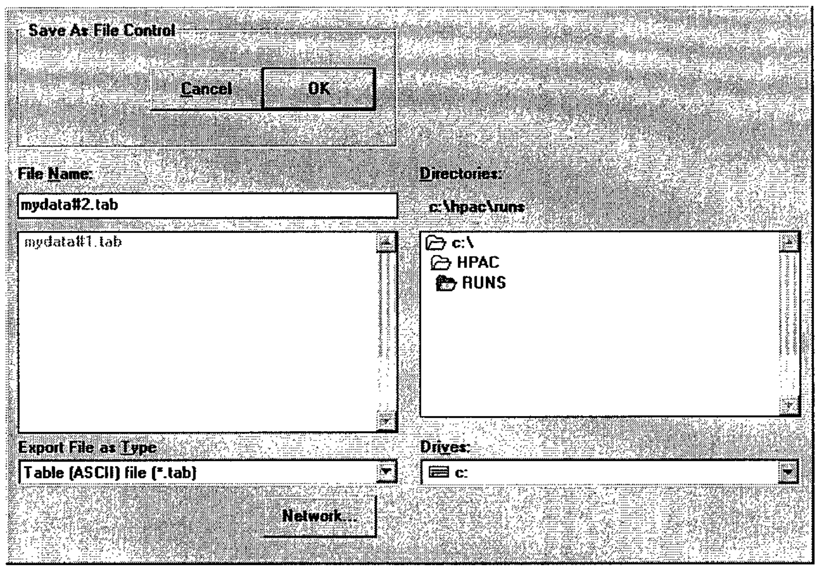

Figure 15: Save As File Control Window

The Table (ASCII) file (*.tab) option in the "Export File As Type" pull down menu is the best choice for data extraction. The file needs to be given a name when you click on "OK" and the Tabular Output Editor window pops up. This is shown in Figure 16.

At first, the table contains no data because the area of interest from Figure 14 needs to be specified. To add the data that is displayed in Figure 14, the "Grid" or "Line" option must be selected. This will allow data to be added to the table. The "Line" option is used for this research because it closely resembles an aircraft route. The line editor is shown in Figure 17.

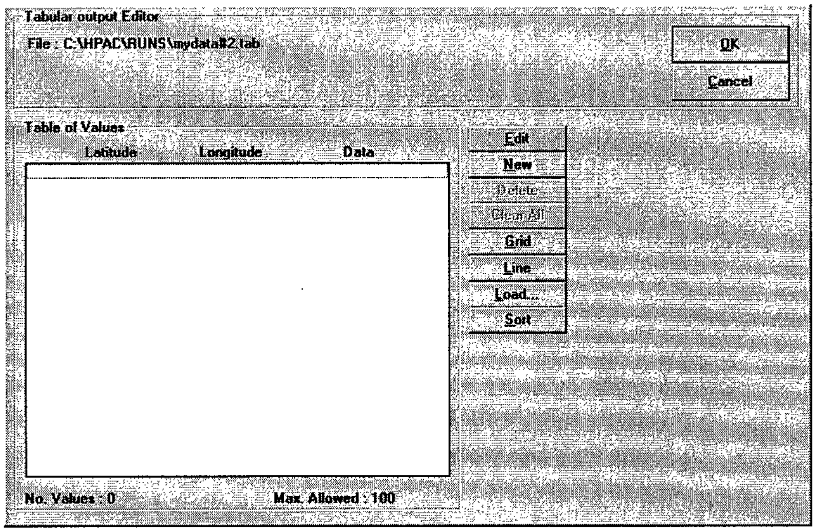

Figure 16: Tabular Output Editor

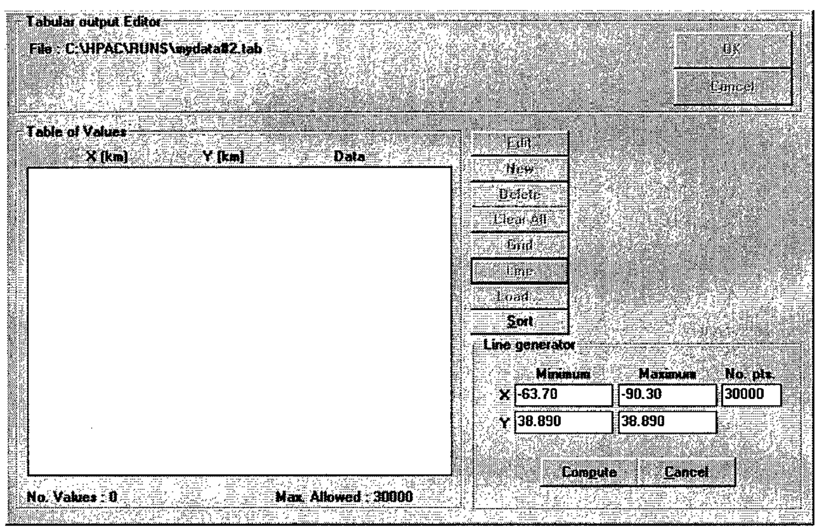

Figure 17: Tabular Output Editor, Line Generator

The appropriate units to use for the X and Y coordinates in the line generator are the coordinate units that are displayed in Figure 14. The max number of data points that is shown depends on which startup option was used. Starting HPAC in the conventional way will let 100 data points be added to the table. Using the Run command, 30,000 data points can be added to the table. Figure 18 shows the 30,000 data point maximum option

for Ultimate Mode in the Run control window. Figure 19 shows a table created by using the "Line" option. This table includes 30,000 data points. Clicking "OK" will save the table data to the file that was specified in Figure 15.

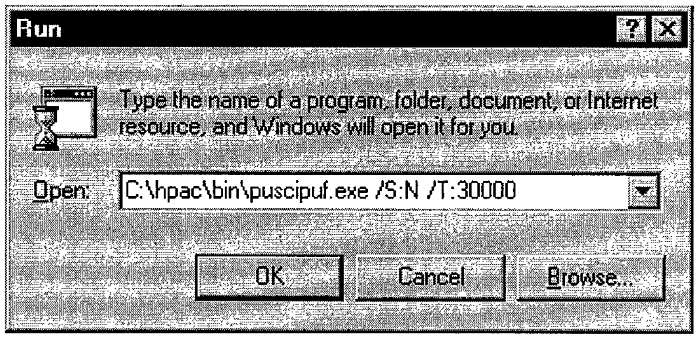

Figure 18: Windows 98 Run Control

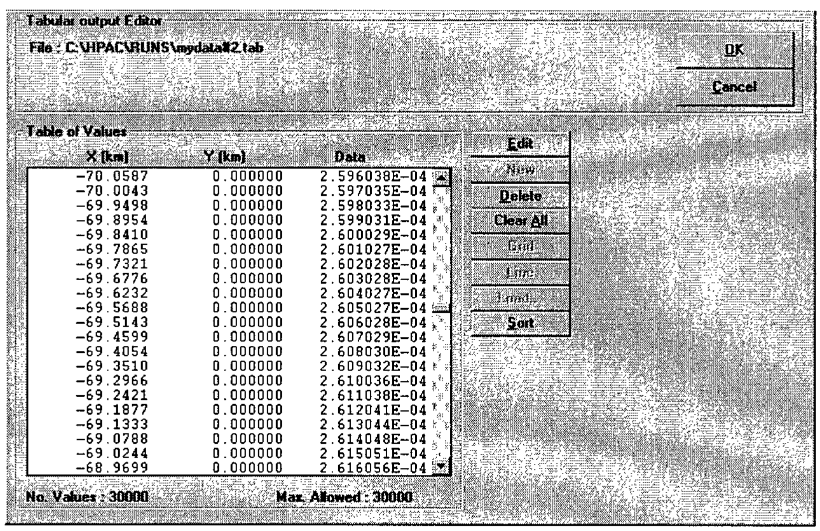

Figure 19: Line of 30,000 Data Points

This data can be accessed using WordPad, Excel, or a FORTRAN Program. It has a "tab" extension but is an ASCII data file. WordPad was used to study the data and FORTRAN was used to read in each data file to calculate the necessary dose to aircrew information.

Chapter III: Radiation, Particle Distributions, and the Initial Stabilized Cloud

A. Background

Nuclear weapons rely primarily on fission (splitting) or fusion (joining) of atomic nuclei to produce desired destructive power results. These processes can also be used together. The power comes from the energy that is released from the fission and fusion processes. The more of the weapon yield that comes from the fission process, the more radioactivity the weapon produces and the more "dirty" the weapon is. Fission weapons are capable of working on their own, but fusion weapons need some sort of fission device to start the process because a fusion reaction requires extremely high temperatures to occur. Because of this, no nuclear weapon is totally clean.

The residual radioactivity that accompanies a nuclear explosion is born from the fission products that result from fission reactions. When fission occurs, one nucleus is split resulting in typically two fission products plus a few neutrons. The fission products then decay to daughter products emitting radiation at the same time. The types of radiation that is emitted depend on the specific fission products. The fission products constitute a very complex mixture of more than 300 different forms (isotopes) of 36 elements that decay, most often, by the emission of beta particles, frequently accompanied by gamma radiation [Glasstone and Dolan: 390].

The altitude, or height of burst (HOB), of the detonation is important because it determines how much mass the radioactive particulates have to cling to the surface of, to distribute into the volume of, and where they get dispersed. The fission products represent about 55 grams of mass per kiloton of fission yield, the casing of the weapon

adds hundreds of kilograms, and for contact surface bursts, there is approximately 0.3 tons of dirt lofted per ton of yield [Bridgman: 403]. Also, Northrop gives the mass of dust lofted, for a contact surface burst (SHOB<5ft/kT$^{1/3}$) as $\frac{M_{SB}}{W} = 0.62 * W^{-0.11}$ where M_{SB} is the lofted mass in kT (kilo-metric tons) and W is the yield in kT (kilo tons) [Northrop: 169]. This extra mass is the carrier material. The higher in altitude the detonation is, the less carrier material there will be because less of the dirt below will be lofted.

For a contact surface burst, the detonation lofts the soil, which is then partially vaporized along with the fission products. The fireball begins at essentially core X-Ray temperature, over 10^7 K [Bridgman: 404]. As the cloud rises, it begins to cool. When it has cooled enough, soil particles start reforming. The fission products with higher melting points than that of soil condensation temperature (about 1600 K) will condense with the soil volumetrically. These particles are called refractory particles. Fission products with melting points that are less than soil will form on the surface of the soil particles because the soil will have already condensed. These particles are called volatile particles. This distribution of radioactivity in and on particles is called fractionation [Bridgman: 405].

B. Particle Distributions

Particle distributions resulting from nuclear detonations have been modeled using power laws, log normal distributions, or combinations of both. Most commonly used is the log normal distribution. The function for a log normal distribution is given as:

$$F(r) = \frac{1}{\sqrt{2\pi}\beta r} e^{-\frac{1}{2}\left(\frac{\ln(r)-\alpha_n}{\beta}\right)^2} \tag{1}$$

where

$F =$ the number of particles of radius r per unit radius (normalized to F_{total})
$r =$ the particle radius,
$\alpha_0 = \ln(r_m)$,
$r_m =$ the mean particle radius of the distribution,
$\beta =$ natural log of the standard deviation of the distribution, or $\ln(\sigma)$,
n = the moment of the function, and
$\alpha_n = \alpha_0 + n\beta^2$

The moment of the log normal distribution is useful because it determines the type of the distribution. For example, a value of n=0 will create a number-size distribution, a value of n=2 will create a surface distribution, a value of n=3 will create a distribution that is volumetric.

Appendix A shows a particle distribution with a moment of n=3 which assumes a totally volumetric distribution. This distribution includes 100 equal activity groups. The program in this appendix can be modified to use a moment of the choice of the user by simply changing the value in the alpha equation. A value of n in between n=2 and n=3 will create a distribution that is somewhere between surface and volumetrically distributed as well as using the sum of two log normal distributions.

The cumulative normal function is given as:

$$F(x) = \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}(x')^2} dx' \tag{2}$$

where

$$x' = \frac{\ln(r) - \alpha_n}{\beta} \tag{3}$$

To find the cumulative normal function value, given a radius (or diameter), the following computational algorithm can be used [Abramowitz: 932].

$$F(x) = 1 - \frac{1}{2}\left[1 + 0.196854x + 0.115194x^2 + 0.000344x^3 + 0.019527x^4\right]^{-4} \text{ for } x>0 \tag{4}$$

This numeric solution is only valid for when x>0. When the values of x are negative, the absolute value of x must be input into the function then $F(x) = 1 - F(Abs(x))$. For small radii, x will be negative, depending on the function parameters used. In order to calculate the cumulative normal function values of the distribution between 0 and 0.5, the absolute value of x must be used and subtracted from one when x is negative. For further exemplification, the FORTRAN program in Appendix A uses this algorithm.

C. Particle Distributions used in NWPN

Eight different distributions are used in NWPN; four different material files and four corresponding cloudtrans files. The files are dependent on whether the scenario in NWPN is above or below ground and if the mode is Standard or Fast. Table 2 summarizes the different files that are used and when.

Table 2: Particle Size Distribution Files in NWPN

Material File	Number of Groups	Corresponding Cloudtrans File	Number of Groups	Mode
U238TN.mtl	20	NEWTRANS.OUT	50	Standard/Above Ground
U238TNF.mtl	10	NEWTRANS.OUT	10	Fast/Above Ground
U238TNB.mtl	20	KDTRANS.OUT	50	Standard/Below Ground
U238TNBF.mtl	10	KDTRANS.OUT	10	Fast/Below Ground

The material files are located in the c:\Hpac\Data\Srcfiles\Wpnagnts\ directory and the cloudtrans files are located in the c:\Hpac\Data\Temp\Nwpntemp\ directory. The material files are permanently stored in the Wpnagnts directory but the cloudtrans files are stored only temporarily in the Nwpntemp directory. The cloudtrans files are replaced anytime a new project is run in HPAC with the newly calculated cloudtrans files. Only one cloudtrans file is ever in the temporary directory. This occurs because the cloudtrans files not only have the particle distributions but have the puff data as well. The puff data is needed by SCIPUFF to transport the radioactivity over time. A description of the cloudtrans file NEWTRANS.OUT is located in Appendix B of this thesis.

The letters in the title of the material file signifies which scenario it gets used for. For example, U238TN.mtl is the standard (non fast) above ground file and a NEWTRANS.OUT gets written in the temporary directory. U238TNBF is the fast, below ground material file and a KDTRANS.OUT file gets written. Thus, the B is for Buried and the F is for Fast. This research does not use the buried files, which means that the KDTRANS.OUT files are never used, but they are included in this description for completeness and could be used if desired.

Tables 3 through 7 list the particle size distributions, for both the material and cloudtrans files, that are used in the stand-alone DELFIC and in NWPN for both standard and fast modes for above ground bursts. The DELFIC 50 group distribution is listed for comparison. These particle sizes are diameters. In equations (1) through (4), the diameter of the particle replaces the radius of the particle and the functions work the same way. The DELFIC group is taken from Jodoin's dissertation [Jodoin: 43]. The upper and lower bound of the distribution, as given in Jodoin's dissertation, are the same

as the NWPN upper bounds and lower bounds. The other numbers in the DELFIC list are the mean diameters of the particle groups. The NWPN file distributions list the boundaries of the particle groups in the distribution. This is why there is one extra number in these lists. HPAC utilizes group boundaries instead of the mean diameter of the groups.

Table 3: DELFIC Particle Size Distribution

DELFIC 50 Group Particle Size Distribution (μm)[1]				
5.160	42.443	94.774	191.190	438.850
9.290	46.620	101.740	205.630	487.940
13.129	50.979	109.140	221.460	547.090
16.685	55.537	117.020	238.880	620.080
20.165	60.313	125.440	258.160	712.960
23.655	65.326	134.450	279.620	836.320
27.198	70.599	144.120	303.670	1010.800
30.826	76.153	154.530	330.820	1284.500
34.564	82.015	165.770	361.750	1815.500
38.430	88.211	177.950	397.360	3268.600

Table 4: NEWTRANS.OUT (U238TN) Particle Size Distribution

NEWTRANS.OUT (U238TN) 50 Group Particle Size Distribution (μm)[2]				
3.536	14.945	63.168	266.986	1128.448
4.084	17.262	72.962	308.381	1303.410
4.717	19.939	84.274	356.194	1505.498
5.449	23.030	97.340	411.421	1738.920
6.294	26.601	112.433	475.210	2008.533
7.270	30.725	129.865	548.890	2319.948
8.397	35.489	150.000	633.993	2679.647
9.698	40.992	173.257	732.291	3095.116
11.202	47.347	200.120	845.830	3575.001
12.939	54.689	231.148	976.973	4129.291
				4769.521

[1] These numbers are mean diameters of particle groups. The upper and lower bounds of the total distribution are 3.563 and 4769.500.

[2] These numbers are diameters of particles and comprise particle group boundaries, not mean diameters of particle groups.

Table 5: U238TN.mtl Particle Size Distribution

U238TN.mtl 20 Group Particle Size Distribution (μm)[3]			
3.536	21.429	129.865	787.016
5.070	30.725	186.204	1128.449
7.269	44.055	266.986	1618.007
10.423	63.168	382.813	2319.951
14.945	90.572	548.890	3326.422
			4769.530

Table 6: NEWTRANS.OUT (U238TNF) Particle Size Distribution

NEWTRANS.OUT (U238TNF) 10 Group Particle Size Distribution (μm)[3]			
3.536	30.725	266.986	2319.947
7.269	63.168	548.889	4769.521
14.945	129.865	1128.447	

Table 7: U238TNF.mtl Particle Size Distribution

U238TNF.mtl 10 Group Particle Size Distribution (μm)[3]			
3.536	30.725	266.986	2319.951
7.269	63.168	548.890	4769.530
14.945	129.865	1128.449	

The NEWTRANS.OUT distributions were modeled after the NewFall particle distribution (upper and lower bound) [Furlong]. A reason for using only 20 groups in the material files while running Standard Mode was not found in this research. Ten groups are used while in Fast Mode for both the material files and the cloudtrans files in order to increase the efficiency of processing time of HPAC calculations [DTRA, 2000: Departures from Legacy Code].

[3] These numbers are diameters of particles and comprise particle group boundaries, not mean diameters of particle groups.

Figure 20 shows different lognormal function fits applied to the NEWTRANS.OUT particle distribution used in HPAC. The other particle distributions used in HPAC have similar plot characteristics but are not included here. The fits include volumetric (n=3), surface (n=2), a sum of two lognormals, and an equal activity per particle size group fit with a mean diameter of 0.407 μm and a geometric standard deviation of 4.0. Norment lists these values in the DELFIC fundamentals reference [Norment, 1979:16] and McGahan mentions that these parameters are the same for the NewFall distributions (hence the NEWTRANS.OUT distribution) as well as the above ground material files (U238TN and TNF) [McGahan]. The purpose of the plot was to see which lognormal fit best represented the particle distribution. Best fit is defined as the straightest line on the graph. For cumulative log normal distribution graphs with a log-probability scale (meaning a log scale on one axis and a probability scale on the other axis) the plot should be a straight line if the data is represented correctly.

For the distribution, the volumetric fit to the data appeared to give the best straight line fit. This fit was a nearly perfect straight line on a log vs. cumulative normal probability scale with the other fits having some obvious curvature.

Tables 8 through 11 show the particle distributions that get used when a below ground (buried) scenario is implemented in NWPN. Again, there is an extra number in each distribution because these numbers are actually the particle group boundaries, not the mean of the group. Also, the authors of KDFOC3 chose to use particle radii whereas the above ground scenario files used particle diameters [McGahan].

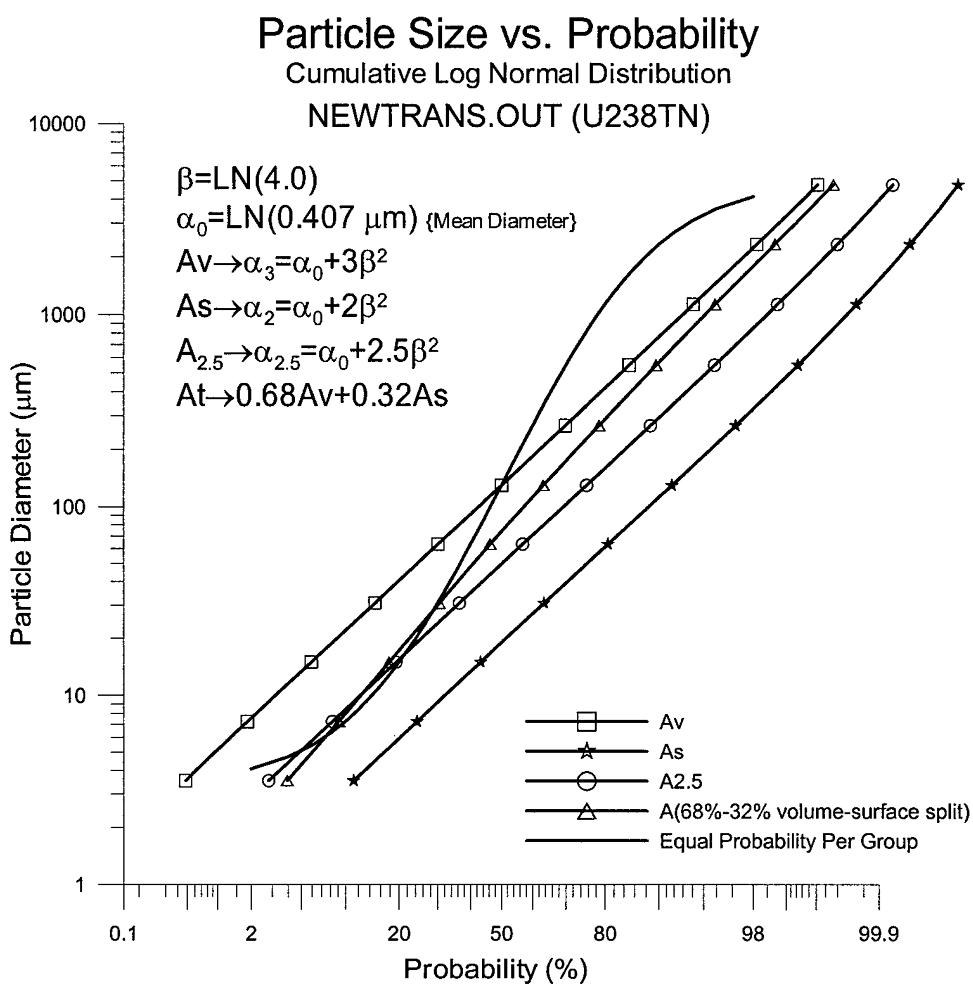

Figure 20: Particle Size Distributions (NEWTRANS.OUT {U238TN})

Table 8: KDTRANS.OUT (U238TNB) Particle Size Distribution

KDTRANS.OUT (U238TNB) 50 Group Particle Size Distribution (μm)[4]				
9.541	24.420	62.505	159.986	409.491
10.481	26.827	68.665	175.751	449.843
11.514	29.470	75.431	193.069	494.171
12.648	32.374	82.864	212.095	542.867
13.895	35.565	91.030	232.995	596.362
15.264	39.069	100.000	255.954	655.128
16.768	42.919	109.854	281.176	719.685
18.421	47.148	120.679	308.884	790.604
20.236	51.795	132.571	339.322	868.511
22.230	56.898	145.635	372.759	954.095
				1048.113

[4] These numbers are particle group boundary numbers in radii.

Table 9: U238TNB.mtl Particle Size Distribution

U238TNB.mtl 20 Group Particle Size Distribution (μm)[4]			
9.541	30.888	100.000	323.746
12.068	39.069	126.486	409.491
15.264	49.417	159.986	517.947
19.307	62.505	202.359	655.128
24.421	79.060	255.955	828.643
			1048.113

Table 10: KDTRANS.OUT (U238TNBF) Particle Size Distribution

KDTRANS.OUT (U238TNBF) 10 Group Particle Size Distribution (μm)[4]			
9.541	39.069	159.986	655.128
15.264	62.505	255.955	1048.113
24.421	100.000	409.491	

Table 11: U238TNBF.mtl Particle Size Distribution

U238TNBF.mtl 10 Group Particle Size Distribution (μm)[4]			
9.541	39.069	159.986	655.128
15.264	62.505	255.955	1048.113
24.421	100.000	409.491	

The KDFOC draft manual listed six different options (parameter values) for geometric mean radii and geometric standard deviations, which are shown in Table 12 [Harvey, et al: 43]. Each option in the manual was fit to the NWPN distributions in order to see which option gave the widest range of cumulative normal probability (0-100%). The specific parameters that these particular below ground distributions were based on were not found in this research. This is the reasoning behind trying to fit the distributions with parameters given below. As a note, the KDFOC3 draft manual lists a surface or low air burst option because KDFOC3, as a stand-alone program, can represent these kinds of scenarios. However, NWPN uses KDFOC3 only for below ground bursts.

Table 12: KDFOC3 Particle Size Distribution Parameters

Surface or Low Air Burst		Small Group	Large Group
	rbl[5] =	2.67	5.02
	delta[6] =	1.39	0.989
Deep Buried DOB>15 ft			
	rbl =	3.8	5.7
	delta =	0.7	0.6
Shallow Buried Burst (Linear Interpolation)			
	rbl =	2.67+sdob(3.8-2.67)/15	5.02+sdob(5.7-5.02)/15
	delta =	1.39+sdob(0.7-1.39)/15	0.989+sdob(0.6-0.989)/15

The surface or low airburst, large group, parameters gave the widest coverage of the particle distributions, with the first group at 0.2% and the last group at 97%. Next, the mean radius (rbl) was shifted from 151.4μm ($e^{5.02}$) to the mean radius of the distributions, 100.0μm, in order to widen the coverage of the data. This further improved the range of the distributions with the first group at 0.88% to 99.12% for the last group. The other options didn't cover the total probability span nearly as well. It seemed odd that above ground parameters worked better for particle distributions that are only used for below ground scenarios in NWPN. No further analysis was done on the below ground particle distributions. Figure 21 shows the plot for KDTRANS.OUT, below ground, particle distribution. The other below ground particle distributions show similar results and are not included in this thesis.

[5] rbl = the natural logarithm of the geometric mean radius
[6] delta = the natural logarithm of the geometric standard deviation

D. Concerns About Particle Distributions Used In NWPN

While researching the particle distributions used in NWPN, several issues were found that remain unresolved. The first issue is the assignment of the NEWTRANS.OUT particle groups to the puff data in the file. Each puff record has a specific particle group that is responsible for the activity in that puff (see Appendix B). It was first assumed, and logically so, that each particle group would get used in at least one puff record in the puff data. It was found that the NEWTRANS.OUT puff data does not include all particle groups. For the NEWTRANS.OUT file included in Appendix A, Figure 22 shows the missing particle groups from the puff data.

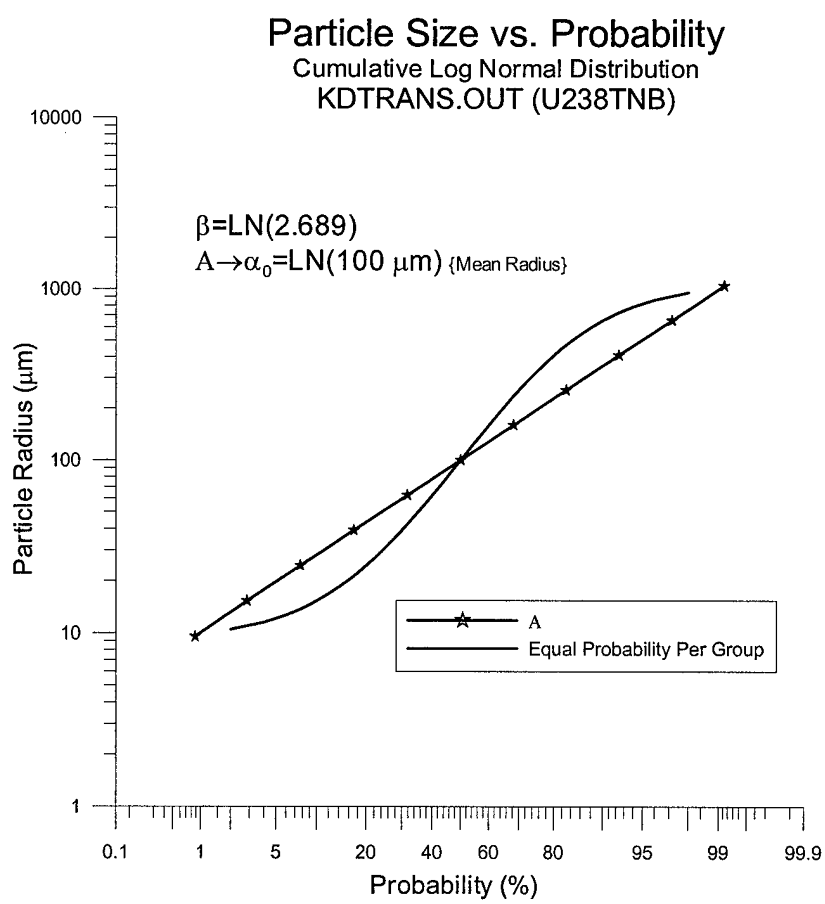

Figure 21: Particle Size Distributions (KDTRANS.OUT {U238TNB})

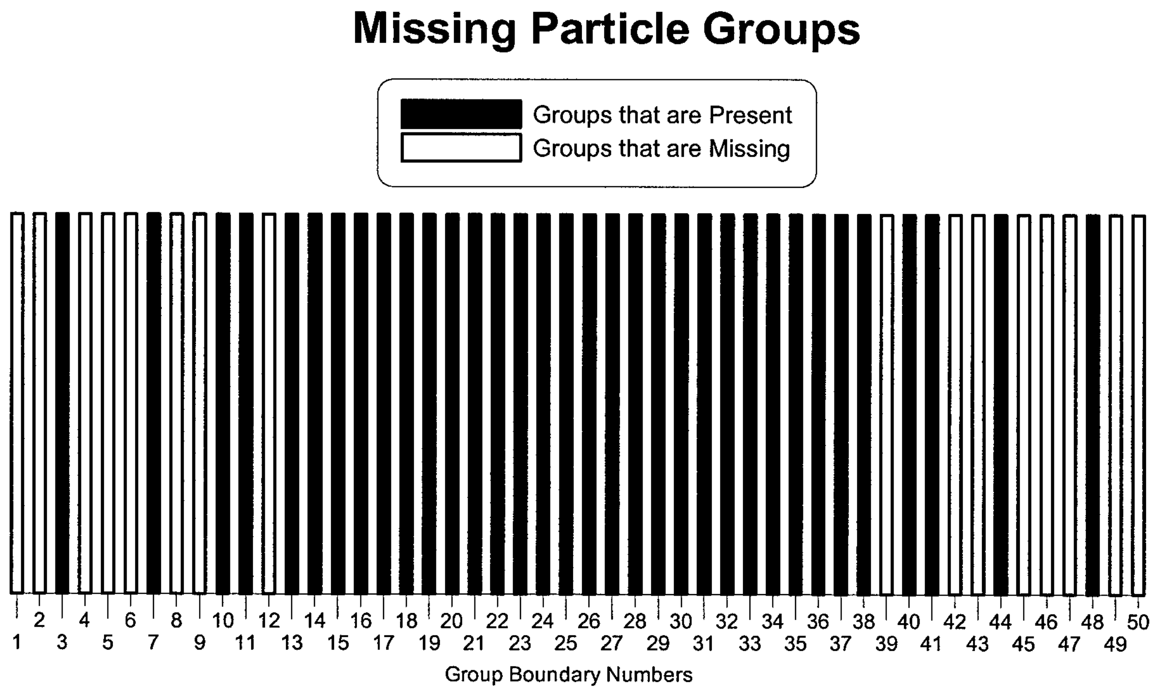

Figure 22: Missing Particle Groups from NEWTRANS.OUT

The missing groups are the groups that did not get assigned any activity during the translation of the disk data to puff data [Furlong]. The missing groups, however, come from the ends of the particle distribution. This begged the question about why they didn't get assigned any activity when the puff data was created. The question was presented to Mr. Furlong of SAIC, but he wasn't able to answer during the time of this research. The source code was available, but time wasn't available to examine it.

Next, the activity that was in the groups that were present was looked at. A first thought was that the activity, also listed in each puff record, was equally distributed throughout the groups that were included in the puff data. Figure 23 shows the percent of total activity that each group in the puff data represents. This figure also shows which particle groups are missing. These missing groups are the zero percent groups. As

shown in the figure, the smaller particle size groups get assigned more total activity than the larger groups do. If a lognormal curve is fitted over the bar chart, as shown in the figure, the bars appear to fit a log normal distribution of activity. If the activity from the missing groups is agglomerated into the groups that are present in the beginning and at the end of the particle distribution, then a near perfect lognormal fit results.

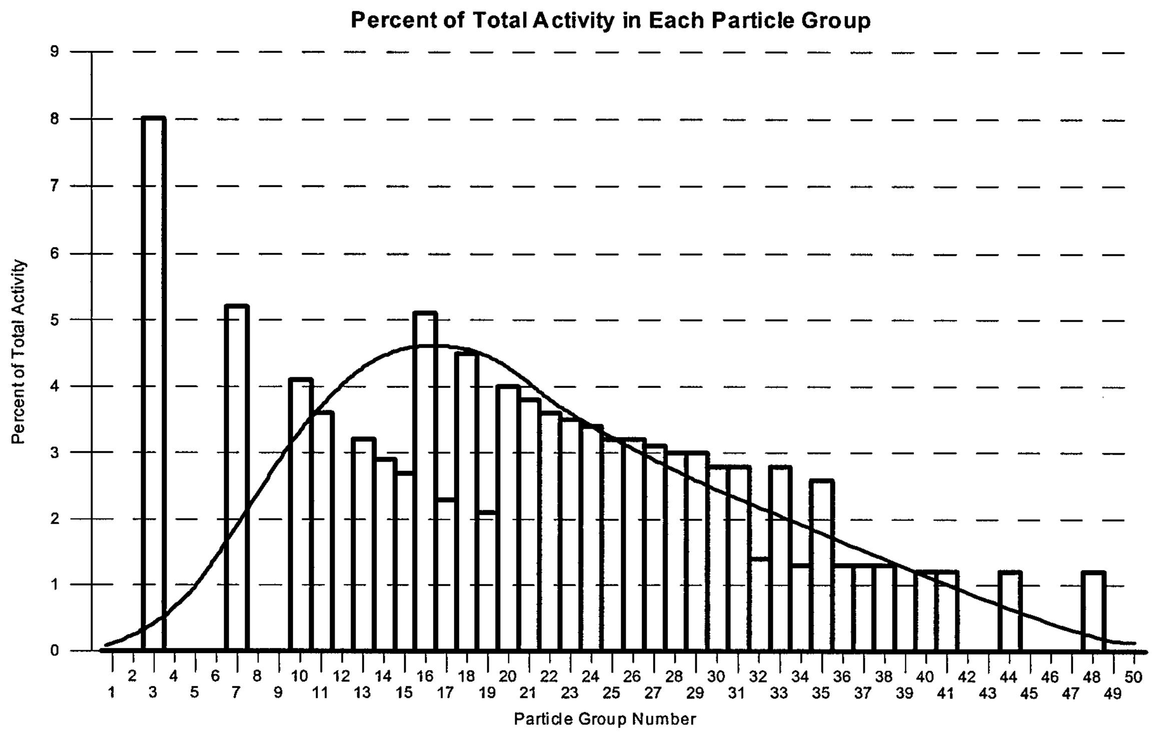

Figure 23: Percent of Total Activity in Each Particle Group

Next, the particle distributions were assigned equal activity in order to see how the results would be plotted. The results have been shown in the particle distribution plots, but have also been re-plotted here next to the DELFIC group and the 100 equal-activity-per-particle group given in Appendix A. Figure 24 shows the particle size group plotted against a probability scale. The 100 equal-activity-per-particle size group is clearly shown as a straight line. The NWPN distributions are shown to not follow this trend.

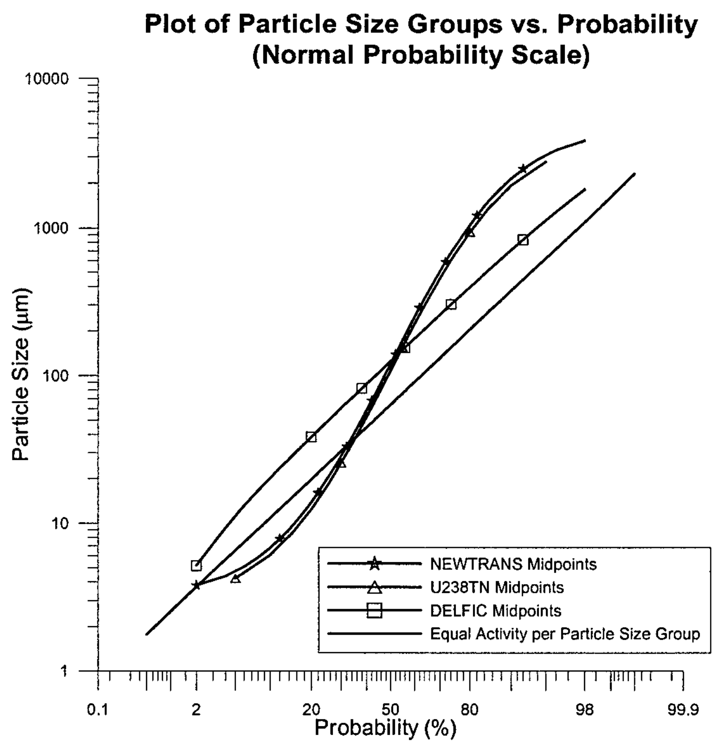

Figure 24: Particle Size Group vs. Probability (Normal Probability Scale)

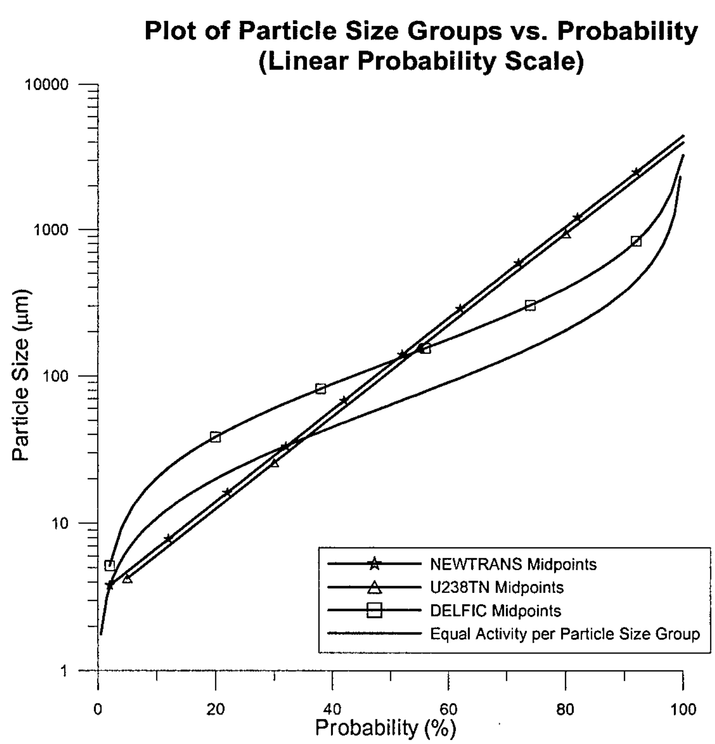

Figure 25: Particle Size Group vs. Probability (Linear Probability Scale)

Figure 25 is the same information just plotted with a linear scale for the probability axis. The equal activity per group distributions that were straight lines are now curves with the NWPN distributions now as straight lines. Clearly, the NWPN particle distribution groups are equally spaced logarithmically while the others are equally spaced based on equal activity per group. Figure 26 reconfirms this fact.

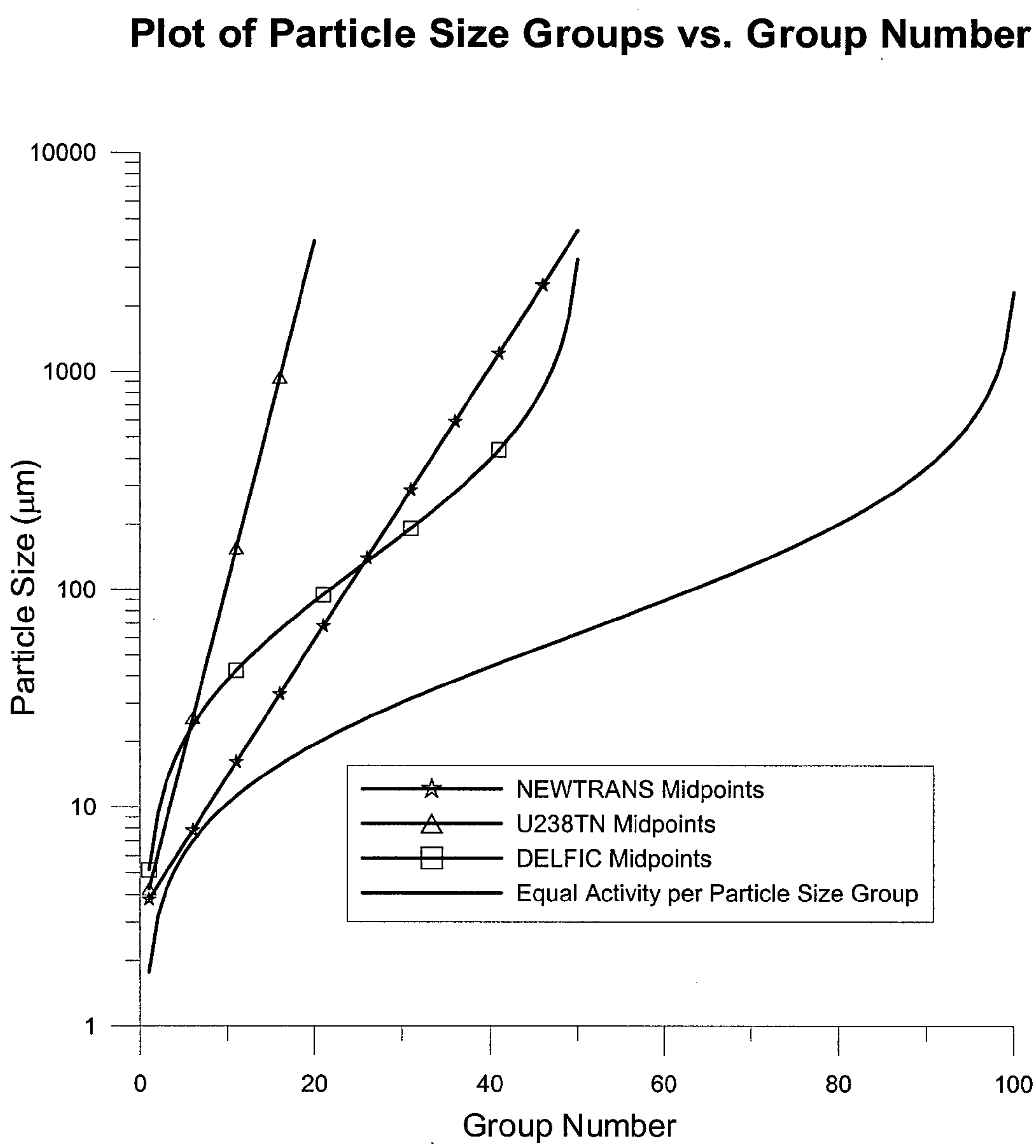

Figure 26: Particle Size vs. Group Number

So the missing particle groups and the assignment of activity in each particle group is a big question that still needs to be resolved in order to fully understand what's going on in NWPN. It is requested of DTRA in their next HPAC user's guide to explain the distribution of activity in the particle groups used in NWPN.

The last concern with the particle distributions is what happens when the 50 groups in a CLOUDTRANS file gets merged into the 20 from the material files. The 50 groups comprise the puff data but then SCIPUFF merges and re-distributes the information into the 20 groups. Even though all activity is conserved [Furlong], the missing groups are still displayed in HPAC output. The question is what happens to the missing groups in this merger.

E. Initial Stabilized Cloud

There are two options in NWPN to build the initial stabilized cloud, for an above ground burst. They are NewFall and DELFIC. DELFIC is a disk tosser code and was developed in order to serve as a standard that other codes could be measured against and for prediction of local radioactive fallout. NWPN uses the Cloud Rise Module (CRM) of DELFIC and many changes and updates over the years have occurred. The DELFIC CRM is a dynamic, one-dimensional, entraining bubble model of nuclear cloud rise. It consists of a set of coupled ordinary differential equations that represent conservation of momentum, mass, heat and turbulent kinetic energy [Norment, 1977: 8]. These differential equations are solved using a fourth-order Runge-Kutta algorithm. Because DELFIC is a disk tosser code, it models the initial radioactive cloud as a series of disks or cylindrically shaped layers. The number of layers in the original DELFIC code is given as:

$$\#\text{ of Layers} = 15 + ln(W) \quad (5)$$

where W is the yield of the weapon in kilotons. In NWPN, the number of layers changes from this yield dependant value to 15 total in Standard Mode and 6 in Fast Mode. Also, the number of particle groups is reduced to 50 (the value in the NEWTRANS.OUT file) from the 100 original DELFIC default groups.

NewFall is essentially an empirical fit of the DELFIC cloud rise output with modifications included to speed up the run time [Lamarche: 24]. Bismarck, ND, is used as ground zero along with atmospheric profiles for this location. The empirical fits that are used in the parameterizations were calculated based on a series of 12 DELFIC predictions using weapon yields of 10, 30, 100, 300, 1000, 3000, and 10,000 kt [Lamarche: 24]. Because NewFall is based on DELFIC, it is also a disk tosser code, but uses a maximum of 12 layers. In NWPN however, the number of layers that NewFall increases to 15 for Standard Mode and 6 for Fast Mode.

F. Transport of Particles

Once the initial stabilized cloud is built, either by NewFall or by DELFIC, the transport of the particles is handled by SCIPUFF (Second-order Closure Integrated Puff). SCIPUFF is an advanced Lagrangian, Gaussian puff model whereas DELFIC and NewFall are disk-tosser codes and the AFIT model is a smearing model. There are two basic aspects of SCIPUFF; a Gaussian Puff method and a turbulent diffusion parameterization based on second-order turbulence closure theories [Sikes: ch1, p1].

Smearing codes, such as the AFIT model, use Gaussian distributions to determine fallout. This is similar to the Gaussian puff representation in SCIPUFF. SCIPUFF uses a collection of Gaussian puffs to represent an arbitrary three-dimensional, time-dependent

concentration field. These three-dimensional Gaussian puffs can be completely described by their special integral moments up to second order, and can be written in the form

$$c(x)=\frac{Q}{(2\pi)^{3/2}(Det(\sigma))^{1/2}}e^{-\frac{1}{2}\left[\frac{(x_i-\overline{x}_i)(x_j-\overline{x}_j)}{\sigma_{ij}}\right]} \tag{6}$$

where the moments, using angle bracket notation to denote an integral over all space, are given as [Sikes: Ch2, p2]:

Zeroth moment (mass)

$$Q=\langle c\rangle$$

First moment (centroid)

$$Q\overline{x}_i=\langle cx_i\rangle$$

Second moment (spread)

$$Q\sigma_{ij}=\left\langle c(x_i-\overline{x}_i)(x_j-\overline{x}_j)\right\rangle$$

The Gaussian puff representation in SCIPUFF has been generalized to include a complete moment-tensor description including off-diagonal moments. This lets SCIPUFF provide an accurate treatment of wind shear effects [DTRA, 2000: Overview of SCIPUFF].

The diffusion model in SCIPUFF is based on second-order turbulence closure, which provides a transport equation for the second-order fluctuation terms. First-order closure prescribes the turbulent fluxes in terms of the local mean gradients using an empirical turbulent diffusivity, but a more general relation can be obtained from a higher-order closure [Sikes: ch2, p5].

The total number of puffs that SCIPUFF will process is given in the CLOUDTRANS file that is generated by NWPN. When SCIPUFF runs, it splits and merges the puffs depending on where they are in the concentration field. A splitting

algorithm divides a puff into two smaller puffs if the puff size exceeds parameters based on the resolution of the wind velocity field, and the algorithm is applied for each of the coordinate directions separately. The parameters that are used can be viewed by clicking the "Options" button as shown in Figure 11: New Project Editor (Advanced Edit Mode). The splitting algorithm is designed to maintain all the puff moments while reducing the overall size and the off-diagonal moments [DTRA, 2000: Overview of SCIPUFF]. Puffs can also be merged when they start to overlap. The merging algorithm that SCIPUFF uses is based on an adaptive multi-grid scheme. The merging criterion is based on the overlap integral between puffs [DTRA, 2000: Overview of SCIPUFF]. SCIPUFF also uses an adaptive time stepping scheme for the transport of particles. The step length is determined by the turbulence time scale, advection velocity, shear distortion rates, and other physical processes so that the step length increases as puffs grow larger and time scales increase [DTRA, 2000: Overview of SCIPUFF].

Particle gravitational settling in SCIPUFF is handled similarly to the McDonald-Davies method described by Bridgman [Bridgman: 410]. This method incorporates aerodynamic drag of the falling particles with the drag coefficient being dependant on the Reynolds number of the particle.

Radioactive decay in SCIPUFF is handled by a decay factor given as [Sikes: Ch8, p 3]

$$f_R = \left(\frac{t - t_R}{1_{hour}}\right)^{-1.3} \tag{7}$$

The activity is defined at 1 hour after release and is carried as a conserved variable in the dispersion calculation. The actual radiation activity is determined from the 1-hour activity using the above decay factor. Radioactive dose and dose rates are estimated from

the surface deposition of the material using empirical decay laws from the NewFall code [Sikes: Ch8, p 3].

G. Vertical Activities (Smearing Model and HPAC)

A comparison of vertical activity per meter of altitude between smearing codes and HPAC was conducted in this study. Vertical activities for various times are calculated by using a Gaussian distribution in the z direction. Equation (8) gives this z Gaussian distribution where G is the total number of particle groups and $z_c^g(t)$ is the altitude where the center of each particle group is located with a standard deviation of σ_z^g.

$$f(z,t) = \sum_{g=1}^{G} \frac{1}{G} \frac{1}{\sqrt{2\pi}\sigma_z^g} e^{-\frac{1}{2}\left(\frac{z - z_c^g(t)}{\sigma_z^g}\right)^2} \tag{8}$$

This Gaussian distribution sums the activity contribution made by all altitudes for each specific altitude. This z distribution is the z distribution that smearing models are based upon. Figure 27 shows activities per vertical meter, $\frac{Ci}{m}$, for various times based on the smearing model.

In HPAC, an instantaneous vertical slice data can be taken to get similar results. The data from HPAC, however, is in $\frac{rem}{hr \bullet m^3}$. Figure 28 plots the data from HPAC with the same time intervals as was done for the smearing model data.

In order to compare the vertical activities of both models directly, the HPAC data or the smearing model data would need to be converted. The relation between the data was studied and is summarized in the next paragraphs.

First, a conversion from dose rate density units (HPAC) to activity per meter (smearing model) will be evaluated. The equation below shows a conversion from $\frac{\text{rem}}{\text{hr}\bullet\text{m}^3}$ to $\frac{\text{Ci}}{\text{m}^3\bullet\text{kg}}$ assuming 1 MeV ($1.602*10^{-13}$ J) gamma rays.

$$\text{Dose Rate Density}\left[\frac{\text{rem}}{\text{hr}\bullet\text{m}^3}\right]\left(\frac{1\,\gamma\text{-Ci}}{3.7*10^{10}\ \frac{\gamma}{\text{s}}*\frac{3600\text{ s}}{\text{hr}}}\right)\left(\frac{1\frac{\text{J}}{\text{kg}}}{1\text{ Gy}}\right)\left(\frac{1\text{ Gy}}{1*10^{-2}\ \gamma\text{ Rad}}\right)\left(\frac{1}{1.602*10^{-13}\text{ J}}\right)$$

$$=4.686\frac{Ci}{m^3\bullet kg}$$

The cubic meter in the denominator above can be reduced to meters if, instead of an instantaneous vertical slice of the cloud within HPAC, an instantaneous horizontal slice is used, with a grid data output (not a line of data). Then multiplying each dose rate density in a cell by the area of each cell, $\Delta\text{x}_{\text{cell}} \bullet \Delta\text{y}_{\text{cell}}$ (essentially numerically integrating), and summing up the data calculated for each cell will give dose rate per vertical meter (z direction). This, when converting as was shown above, will give units of $\frac{\text{Ci}}{\text{m}\bullet\text{kg}}$. The problem with finding the conversion factor lies with trying to eliminate the kg in the denominator. These units represent activity per vertical meter of altitude per kg of atmosphere. Finding this quantity of atmosphere is beyond the scope of this research. Next, an approach to convert the smearing model units to HPAC units was studied.

Dose rate for the smearing model is given as [Bridgman: 417]:

$$\dot{D}(x,y,x,t)=581\ \frac{A(x,y,z,t)}{\rho_{alt}}\ \left[\frac{\text{R}}{\text{hr}}\right] \tag{9}$$

Then, applying the following will convert to required dose rate units.

$$\left(581\ \frac{R}{hr}\right)\left(\frac{0.00877\ \frac{J}{kg}}{1\,R}\right)\left(\frac{1\ Gray}{1\ \frac{J}{kg}}\right)\left(\frac{100\ \gamma-Rad}{1\ Gray}\right)\left(\frac{1\ \mathrm{Re}m}{1\ \gamma-Rad}\right)=509.5\left[\frac{\mathrm{Re}m}{hr}\right]$$

If $A(x,y,z,t)=A(t)_{1-hour}f(z,t)f(x,t)f(y,t)$, where $f(z,t)$ is what is plotted in Figure 27, and

$$f(x,t)=\left\{\frac{1}{\sqrt{2\pi}\sigma_x(t)}e^{-\frac{1}{2}\left[\frac{x-v_x t}{\sigma_x(t)}\right]^2}\right\}\ \text{and}\ f(y,t)=\left\{\frac{1}{\sqrt{2\pi}\sigma_y(t)}e^{-\frac{1}{2}\left[\frac{y}{\sigma_y(t)}\right]^2}\right\}$$

where t is the aircraft crossing time, and the aircraft crosses the cloud at the centerline, Dose rate density units emerge. Because the aircraft crosses the cloud at the centerline, the exponential terms in the x and y distribution equations above reduce to

$$f(x,t)=\frac{1}{\sqrt{2\pi}\sigma_x(t)}\ \text{and}\ f(y,t)=\frac{1}{\sqrt{2\pi}\sigma_y(t)}$$

where

$$\sigma_x^2=\sigma_{rise}^2+\sigma_{diffusion}^2,$$

$$\sigma_y^2=\sigma_{rise}^2+\sigma_{diffusion}^2+\sigma_{shear}^2,$$

$$\sigma_{rise}^2=1.609^2 e^{2\left(0.70+\frac{1}{3}\ln(Y_{Mt})-\frac{3.25}{4.0+(\ln(Y_{Mt})+5.4)}\right)},$$

$$\sigma_{diffusion}^2=\frac{8\sigma_{rise}^2 t^*}{T_c}\ \text{where}\ t^*\le 3\ hours\ \text{and}\ T_c=12\left(\frac{z_c^o}{18.28}\right)-2.5\left(\frac{z_c^o}{18.28}\right)^2, and$$

σ_{shear}^2 is ignored.

Compiling these terms together yields

$$\dot{D}(x,y,x,t)/\,density=509.5\ \frac{A(t)_{1-hour}f(z,t)}{\rho_{alt}\bullet 2\pi\bullet\sigma_x\bullet\sigma_y}\ \left[\frac{\text{Rem}}{\text{hr}\bullet\text{m}^3}@\text{1-hour}\right] \tag{10}$$

and is shown along with the HPAC results in Figure 29. This figure shows about four orders of magnitude between the two sets of results. It has been suggested that the huge

difference lies in the fact that all of the activity at a certain altitude, z, is agglomerated into a specific point that a detector would read by using the x and y deviations as shown in the previous equations [Bridgman: 2001]. Certainly, the HPAC data, using a vertical slice, does not represent this type of agglomeration. Also, the reason behind this difference may lie within HPAC and the way the data is handled there. As with the particle distribution question, it is requested that DTRA, possibly in the HPAC Help program, explain particle settling/vertical activity distribution in order to better understand these results.

Figure 27 and Figure 28 can be compared indirectly, however. Both curves show decreases in the amount of activity per meter and dose rate density over time due to particle settling. The smearing model curves were computed with 100-group particle distributions as calculated in Appendix A. Only 20 groups are used in HPAC. This could be the reason that the curves generated from data given by HPAC are not smooth like the smearing model curves. Larger separation distances in particle groups caused by settling could possibly cause the dose rate density decreases and sudden increases on the HPAC curves. With a 100-group distribution, the separation distance will surely be smaller between adjacent groups because the differences in particle sizes will be smaller resulting in smaller settling rate differences between two successive groups.

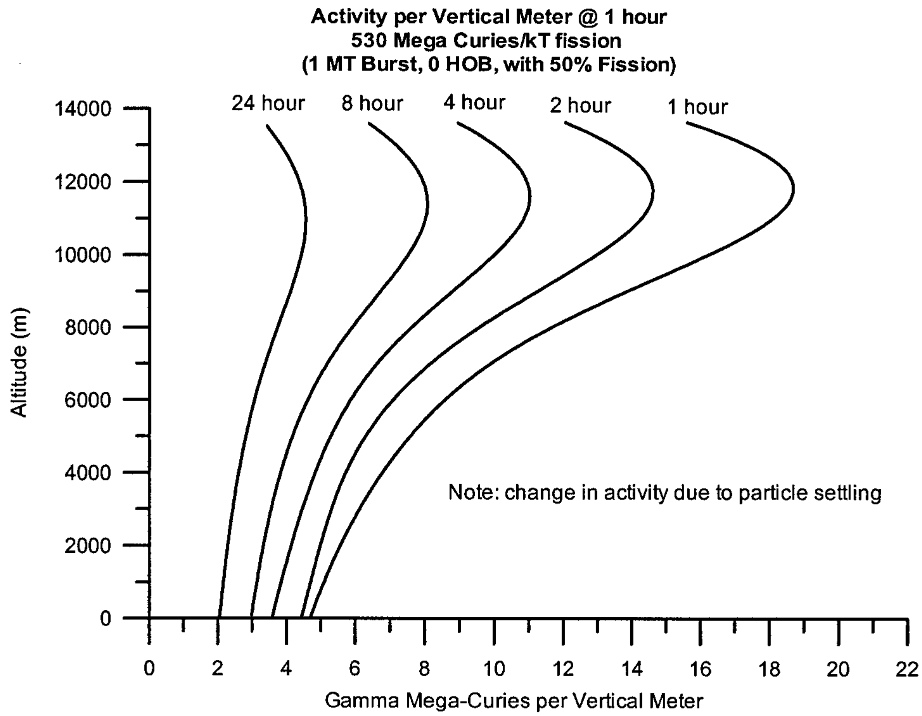

Figure 27: Vertical Activity per Meter of Altitude (Smearing Model)

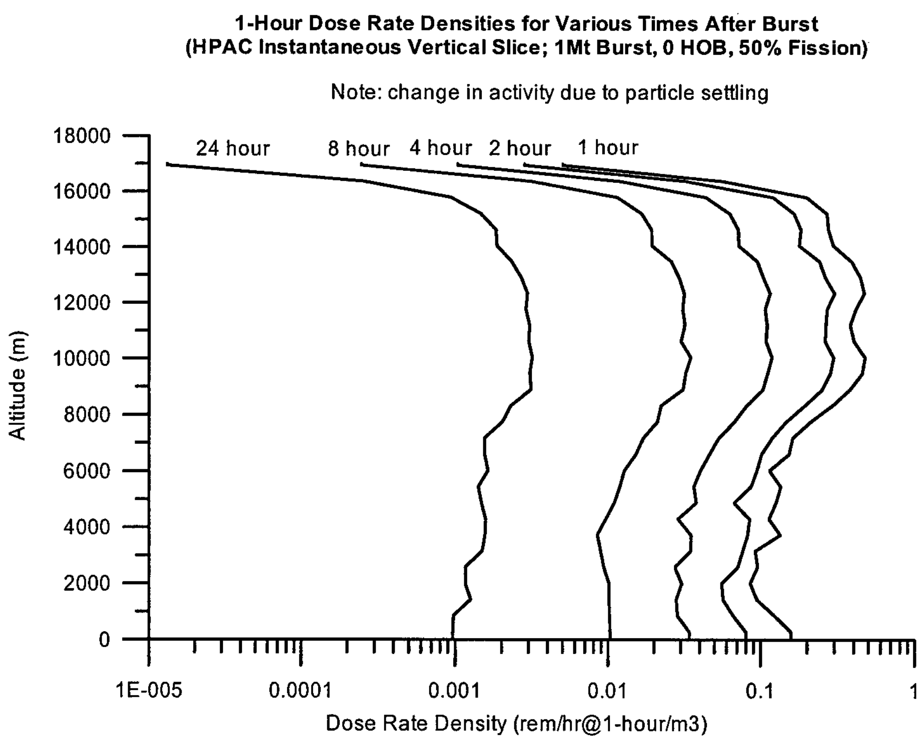

Figure 28: HPAC Dose Rate Density as a Function of Altitude

Comparison Between Corrected Smearing Model and HPAC

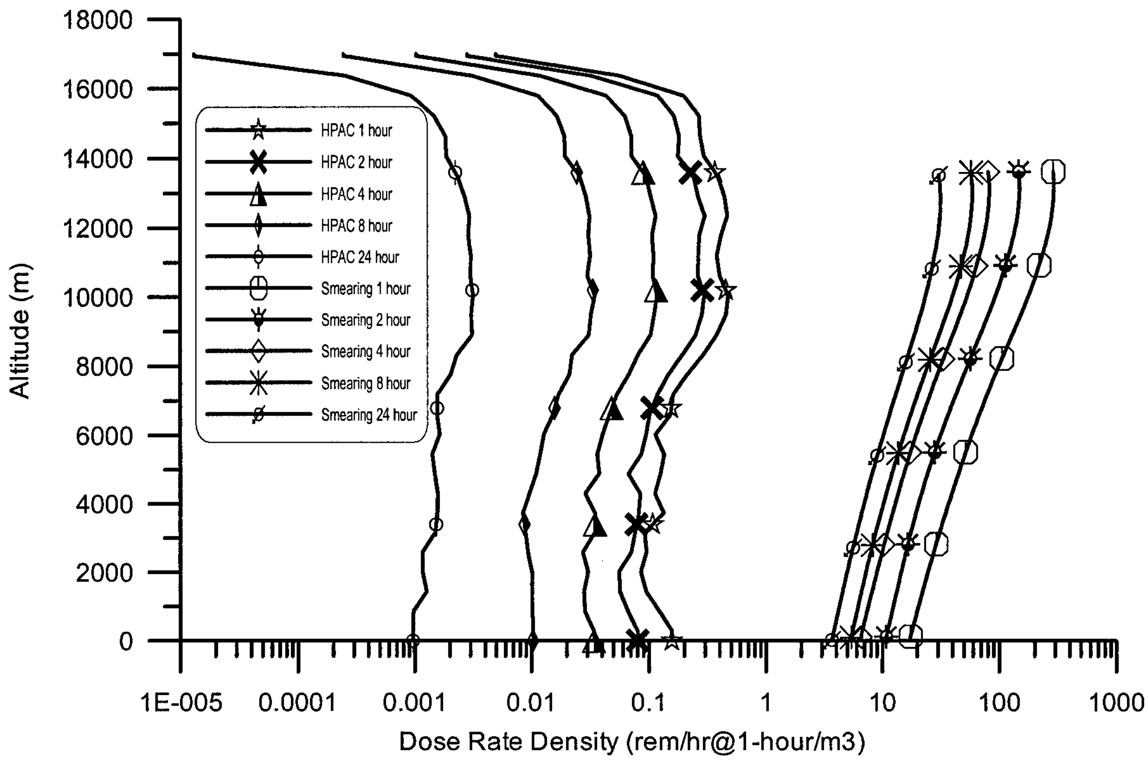

Figure 29: Comparison of Smearing and HPAC Dose Rate Densities

Chapter IV: Dose Analysis

A. Background

There are four different ways that an aircraft and its crew can be exposed to radiation when flying through a radioactive cloud resulting from a nuclear weapon burst. They are ground-shine, skin-shine, sky-shine, and cabin ingestion.

Ground-shine is exposure to radiation, which results from the fallout of a nuclear burst. Hickman and Kling have shown that ground-shine is a negligible dose factor for aircraft that fly at least a few gamma mean free paths above the ground, ~ 130 m for 1MeV gamma rays at sea level. Hickman calculated that for an aircraft that is flying at an altitude of only 305 meters, the dose rate at the aircraft is equal to 10^{-11} times the ground activity. At an altitude of 9150 meters, he calculated that the dose at altitude is 10^{-29} times the ground activity [Hickman: 20]. Therefore ground-shine will be disregarded in this study.

Skin-shine results from radioactivity that adheres to the outer surface of the aircraft during transit through the cloud. The activity, in Ci, due to skin-shine is

$$A_{skin} = A''(y, z, t_o) \bullet A \bullet S \tag{11}$$

where $A''(y, z, t_o)$ is the activity per area (Ci/m^2), A is the effective cross-sectional area, and S is a "sticking coefficient" [Bridgman: 431]. Bridgman goes on to say that the sticking coefficient seems to be small except for cracks and other irregularities and as a result is rarely significant. Also, dust particles small enough to stay airborne for significant periods may not be able to penetrate the aerodynamic boundary layer outside the skin of the aircraft and attach to the skin in large enough numbers to cause significant

dose to the crew inside. Thus, skin-shine will also be disregarded due to both insignificance and being beyond the scope of this study. Sky-shine and cabin ingestion dose will be discussed in more detail later in this chapter.

The aircraft that are used in this study are the KC-135 and the B-1B. These aircraft were chosen because they are the aircraft that Conners used for his analysis and the dose to aircrew that this study calculates will be compared to what Conners calculated. His baseline aircraft was the KC-135 for computing sky-shine and cabin ingestion. The B-1B is included in this study because Conners was able to obtain air filter information for this aircraft. This information is needed in order to accurately compute cabin ingestion. Table 13 lists relevant aircraft data that is used.

Table 13: Basic Aircraft Data

Basic Aircraft Data

Aircraft:	Velocity	Cabin Mass	Cabin Area	Cabin Radius	Pressurized Volume	Mass Flow Rate
KC-135:	231.5 m/s	18,073 kg	310 m^2	1.79 m	232.2 m^3	50 kg/min
B-1B:	279.2 m/s	11,511 kg	107.9 m^2	1.07 m	28.3 m^3	17 kg/min

The internal dimensions of the aircraft cabin are assumed to be a cylinder. However, the entire aircraft cylinder is not pressurized. Conners developed a "pseudolength" to allow for variations of the simplified cylindrical model compared to real aircraft. This length represents the value obtained by dividing the pressurized volume of the cabin by the cross sectional area and is given by Equation (12) [Conners: 36].

$$"Pseudolength" = \frac{\text{Pressurized Volume}}{\pi\, r^2} \tag{12}$$

This is the cabin length that is used in the volume integral that will be described later in this chapter. Conners mentions that length rather than radius is chosen to vary because the radius is the most accurately known, is the least variable dimension, and because the cabin geometry factor is more sensitive to radius than length [Conners: 36]. This approach as well as a simple spherical model will be discussed in more detail later in this chapter.

B. Sky-Shine Shielding

The aircraft can shield radiation, due to sky-shine, by it's skin, structure, and its internal components. Attenuation of radiation is given by

$$A = A_o e^{-\left(\frac{\mu_t}{\rho}\right)_{mat} MI} \quad [\text{Ci}] \tag{13}$$

where A_o is the incident gamma activity, μ_t/ρ is the mass attenuation coefficient of the shield material in m^2/kg for a given gamma ray energy, MI is the mass integral in kg/m^2, and A is the attenuated gamma activity. Dose, dose rate, or dose rate densities, can be substituted in the above equation, as well, to get attenuated values. HPAC outputs dose rate densities, which are used in this study. The mass integral is found by using the aircraft data in Table 13 in the following equation (as used by Conners) [Conners: 97].

$$MI = \frac{\text{Cabin Mass}}{\text{Cabin Surface Area}} \quad \left[\frac{\text{kg}}{\text{m}^2}\right] \tag{14}$$

A gamma transmission factor, $T\gamma$, is now defined as the unitless exponential term in Equation (13) and is shown below.

$$\text{T}_\gamma = e^{-\left(\frac{\mu_t}{\rho}\right)_{mat} MI} \tag{15}$$

The following assumptions need to be made in order to use the gamma transmission factor:

1) The mass and area of the wings, tail, fuel, and in bombers, the fuselage aft of the crew compartment are ignored.
2) The cabin wall is homogeneous. It is composed of a single material (aluminum), which is evenly distributed with a single thickness.

The wings and tail in the first assumption contribute little to the overall shielding of radiation because they subtend small angles as observed from the cabin. The fuel is variable and is ignored for simplicity. The second assumption is valid because about 80% of typical aircraft structure and equipment is aluminum and most of the remaining material is low atomic number material with similar mass attenuation coefficients in the 1 MeV range [Conners: 38].

C. Sky-Shine Dose

As an aircraft approaches a radioactive cloud, it will not be exposed to significant radiation until it is within a few gamma mean free paths of the cloud. The radioactivity will increase as the aircraft approaches the center of the cloud, and then will start to decrease. Figure 30 illustrates this point. This figure shows an HPAC dose rate density distribution for the baseline input case weapon given in Chapter I and is a horizontal slice of the burst cloud at 10,000 meters at 4 hours after burst.

Appendix C shows an example of HPAC output data. Only the first page is shown because there are 30,000 data points and would take up a lot of unnecessary space in this document. The data has units of dose rate density and is given at intervals along a line through the cloud. The spacing of these intervals depends on the number of data

points that are used and the minimum and maximum coordinate values. An iterative looping program was created, using FORTRAN, to process the data to calculate dose to aircrew. This program is included as Appendix D.

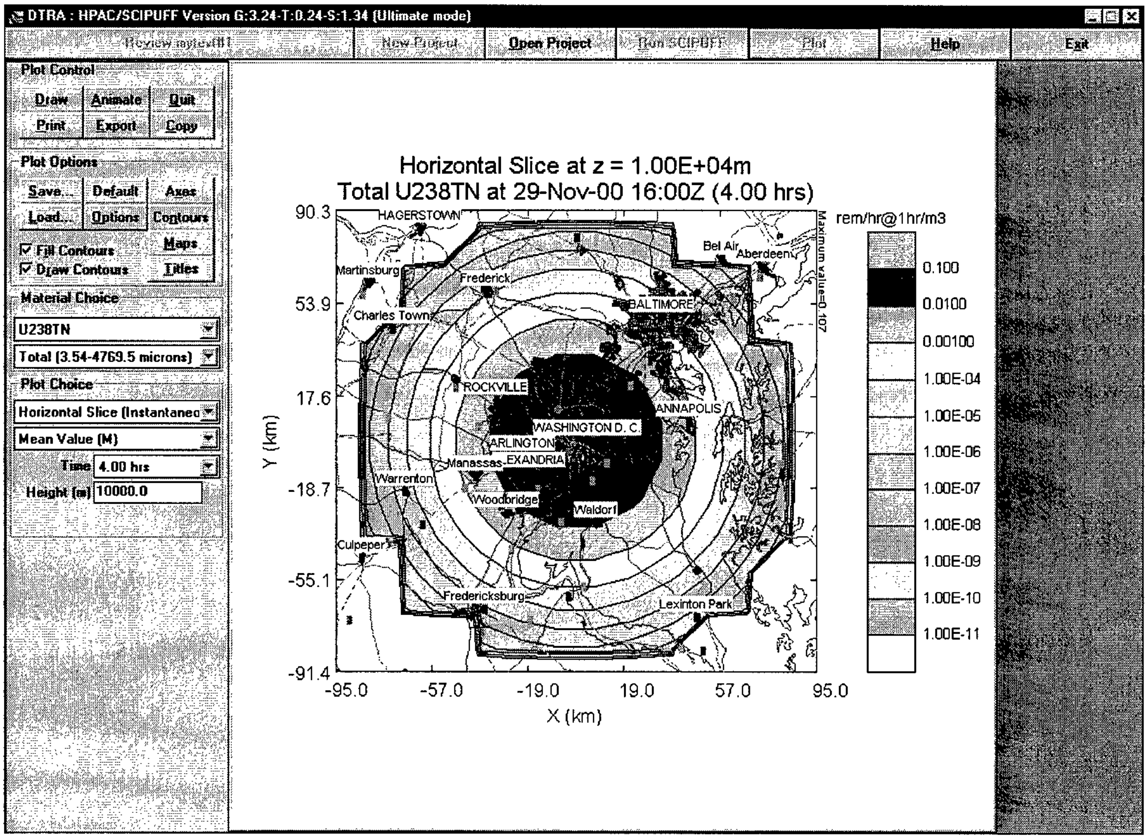

Figure 30: HPAC Dose Rate Density Distribution in the Cloud

Appendix C shows an example of HPAC output data. Only the first page is shown because there are 30,000 data points which would take up a lot of unnecessary space in this document. The data has units of dose rate density and is given at intervals along a line through the cloud. The spacing of these intervals depends on the number of data points that are used and the minimum and maximum coordinate values. An iterative looping program was created, using FORTRAN, to process the data to calculate dose to aircrew. This program is included as Appendix D.

Hickman, Kling, and Conners based their theses on smearing codes. HPAC, with the aid of SCIPUFF, outputs dose rate density information. The main problem in this thesis was to develop a model that would correctly calculate dose to an aircrew from HPAC output data. Finding a solution to this problem was accomplished by first going through the Gaussian distribution equations that smearing codes use in order to know exactly what conversion multiplier the dose rate densities had to be multiplied by.

The activity density (Ci/m^3) of a cloud at any location and at any time is given by:

$$A(x',y',z',t) = A(t)\left\{\frac{1}{\sqrt{2\pi}\sigma_x(t)}e^{-\frac{1}{2}\left[\frac{x-v_x t}{\sigma_x(t)}\right]^2}\right\}\left\{\frac{1}{\sqrt{2\pi}\sigma_y(t)}e^{-\frac{1}{2}\left[\frac{y}{\sigma_y(t)}\right]^2}\right\}\left\{\sum_{g=1}^{G}\frac{1}{G}\frac{1}{\sqrt{2\pi}\sigma_z^g}e^{-\frac{1}{2}\left[\frac{z-z_c^g(t)}{\sigma_z^g}\right]^2}\right\} \tag{16}$$

Taking the assumption that ground-shine is negligible, the differential contribution to dose rate at a detector located at x, y, z in the cabin of an aircraft from a differential volume of the cloud at some location x’, y’, z’ (shown in Figure 31) is:

$$\frac{d\dot{D}(x,y,z,t)}{dVol} = C_u A(x',y',z',t)\frac{e^{-\int\left(\frac{\mu_t}{\rho}\right)_{air}\rho ds}}{4\pi s^2}\left(\frac{\mu_a}{\rho}\right)_{air}\left(h\nu_{avg}\right)BUF \quad \left[\frac{\text{rem}}{\text{hr}\bullet\text{m}^3}\right] \tag{17}$$

where

C_u is a units conversion multiplier, $\left[\frac{\text{rem}\bullet\text{kg}}{\text{hr}\bullet\text{J}\bullet\text{Ci}}\right]$,

A(x’,y’,z’,t) is the activity density, $\left[\frac{Ci}{m^3}\right]$,

μ_t/ρ and μ_a/ρ are the mass attenuation and absorption coefficients for air, $\left[\frac{\text{m}^2}{\text{kg}}\right]$,

ρ is the density at altitude,

ds is the differential pathlength of the radiation gammas,

$h\nu_{avg}$ is the average gamma-ray energy, [J],

BUF is the build up factor, which is taken as one, and

$4\pi s^2$ is for spherical divergence with s as the slant range.

BUF is one because unlike X-rays, γ-rays do not build up their energy along their mean free paths. Because the average gamma mean free path is tens of meters and because the standard deviation of the horizontal distributions, σ_x and σ_y, are of the order of kilometers, the activity at all locations, A(x', y', z', t) can be approximated by the value at the detector location (x, y, z).

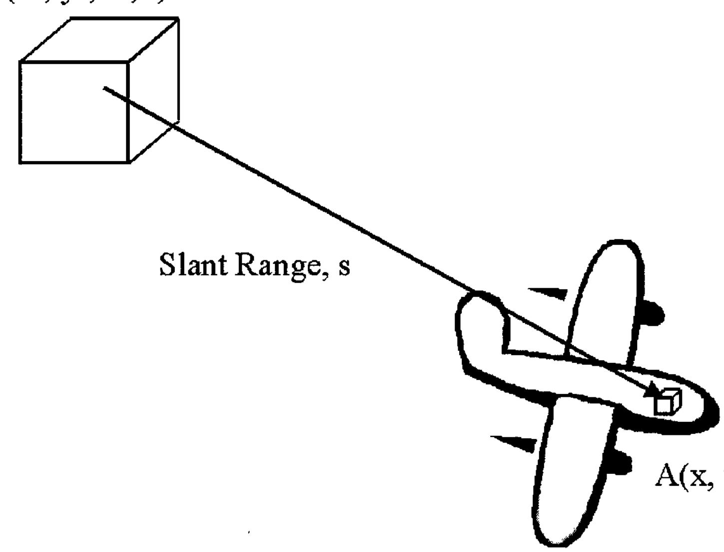

Figure 31: Slant Range

Equation (17) has units of dose rate density, the same units as the data that HPAC outputs. In order to find the necessary volume multiplier to convert from dose rate density at a point to dose rate at a point, Equation (17) must be integrated with respect to volume. Doing this yields

$$\dot{D}(x,y,z,t) = \iiint C_u A(x',y',z',t)\left(\frac{\mu_a}{\rho}\right)_{air}\left(h\nu_{avg}\right)\frac{e^{-\int\left(\frac{\mu_t}{\rho}\right)_{air}\rho ds}}{4\pi s^2}\, \mathrm{dx'\,dy'\,dz'}\left[\frac{\mathrm{rem}}{\mathrm{hr}}\right] \quad (18)$$

which simplifies to

$$\dot{D}(x,y,z,t) = C_u A(x',y',z',t)\left(\frac{\mu_a}{\rho}\right)_{air}\left(h\nu_{avg}\right)\int_0^{\infty}\frac{e^{-\int\left(\frac{\mu_t}{\rho}\right)_{air}\rho ds}}{\cancel{\left(4\pi s^2\right)}}\cancel{\left(4\pi s^2\right)}ds \left[\frac{\text{rem}}{\text{hr}}\right] \quad (19)$$

Equation (19) can be directly integrated to give

$$\dot{D}(x,y,z,t) = \left\{C_u A(x',y',z',t)\left(\frac{\mu_a}{\rho}\right)_{air}\left(h\nu_{avg}\right)\right\}\left\{\frac{1}{\left(\frac{\mu_t}{\rho}\right)_{air}\rho}\right\} \left[\frac{\text{rem}}{\text{hr}}\right] \quad (20)$$

This multiplier in the second set of brackets, $\frac{1}{\left(\frac{\mu_t}{\rho}\right)_{air}\rho}$, is simply just the mean free path of the gamma radiation at the aircraft altitude and is the multiplier that is also used to translate the HPAC dose rate density output data to dose rate data. It has units of meters but can be used nevertheless because Equation (18) is in rem/hr already. The mean free path is just the byproduct of the integration.

Next, the dose rates have to be converted to dose to aircrew. Smearing codes simply integrate Equation (20) with respect to time. The data from HPAC cannot be handled this way because it is given in intervals, not as a continuous function. Instead, dose is calculated by multiplying the dose rate that is measured in each cell (interval) of the HPAC output data (from Equation (20)) by the time that the aircraft was in that cell, t_{cell}.

$$D(x,y,z,t)_{cell} = \dot{D}(x,y,z,t) * t_{\text{cell}} \; [\text{rem}] \quad (21)$$

where

$$t_{\text{cell}}\,[\text{hr}] = \frac{\Delta x_{\text{cell}}\,[\text{m}]}{v_{\text{aircraft}}\left[\frac{\text{m}}{\text{s}}\right]*3600\left[\frac{s}{hr}\right]} \quad (22)$$

The data that HPAC outputs, for a horizontal slice, is 1-hour data meaning that the dose rate densities at 1-hour after burst are reported. Different values are reported at different times due to particle settling, not radioactive decay. Because of this, the dose data needs to be multiplied by a decay factor to correct for radioactive decay from the 1-hour calculated dose values. HPAC uses a $t^{-1.3}$ decay law when it calculates fallout. The same decay law will be used here. Dose at a specified time in each cell is given as

$$D(x,y,z,t) = D(x,y,z,1)t^{-1.3} \tag{23}$$

To get the final dose that an aircrew receives, the dose in Equation (23) is multiplied by the gamma transmission factor calculated in Equation (15). This gives total sky-shine dose in each cell and is summarized by Equation (24).

$$Final\ D(x,y,z,t)_{\text{@ time in cell, i}} = Dose\ Rate\ Density_{1-hour}\left(\frac{1}{\left(\frac{\mu_t}{\rho}\right)_{air}\rho_{altitude}}\right)\left(t_{\text{cell}}\right)\left(t^{-1.3}\right)\left(T_\gamma\right) \tag{24}$$

The final sky-shine dose that the aircrew receives is just the sum of the doses from each cell, or

$$\text{Total Sky-Shine Dose} = \sum_{i=1}^{\text{\# of cells}} Final\ D(x,y,z,t)_{\text{@ time in cell, i}} \tag{25}$$

D. Cabin Ingestion Dose

When an aircraft flies through a radioactive cloud, it sweeps out all of the activity along its route. Because HPAC gives dose rate densities, the cabin ingestion dose to the aircrew is determined by first finding an equivalent air inlet area. This effective inlet area given by

$$EIA = \frac{\Omega}{v_{aircraft}\rho_{air}} \quad \left[\mathrm{m}^2\right] \tag{26}$$

where Ω is the mass flow rate of air into the cabin from the engine compressor in kg/sec, v_{aircraft} is the velocity of the aircraft, and ρ_{air} is the density of air at the altitude that the aircraft is flying at. The effective inlet area multiplied by the width of each cell, Δx, gives a "pseudovolume" (PSV), which, when multiplied by the dose rate densities, gives the total dose rate that has entered the cabin as shown by the next two equations.

$$PSV = EIA * \Delta x_{cell} \quad \left[\mathrm{m}^3\right] \tag{27}$$

$$\text{Dose Rate}_{\text{cabin}}\left[\frac{\text{rem}}{\text{hr}}\right] = \text{Dose Rate Density}\left[\frac{\text{rem}}{\text{hr} \bullet \text{m}^3}\right] * \text{PSV}\left[\mathrm{m}^3\right] \tag{28}$$

It was assumed in Chapter I that all of the activity that enters the cabin will remain in the cabin and will stay suspended throughout the duration of the mission. This will give an upper bound to this problem. Also, the dose rate will not change significantly during transit of the cloud.

Once the dose rate is inside the cabin, a redistributed dose rate density (RDDRD) is calculated based on the pressurized volume of the cabin, $\mathrm{PV}_{\mathrm{cabin}}$, and is given by

$$\text{RDDRD}\left[\frac{\text{rem}}{\text{hr} \bullet \text{m}^3}\right] = \frac{\text{Dose Rate}_{\text{cabin}}\left[\frac{\text{rem}}{\text{hr}}\right]}{\text{PV}_{\text{cabin}}\left[\mathrm{m}^3\right]} \tag{29}$$

The dose rate at the center of a cylindrical cabin then becomes

$$\dot{D} = \left(RDDRD\right)\int_{-H}^{H}\int_{0}^{R}\int_{0}^{2\pi}\frac{e^{-\left(\frac{\mu_t}{\rho}\right)_{air}\rho(r^2+z^2)^{\frac{1}{2}}}}{4\pi(r^2+z^2)}\, r\, d\theta\, dr\, dz \quad \left[\frac{\text{rem}}{\text{hr}}\right] \tag{30}$$

where R is the radius of the cabin and H is one half of the pseudolength. This triple integral in Equation (30) simplifies to a double integral because the first integral just

gives a multiple of 2π. The double integral can then be solved numerically [Burden and Faires: 236]. The result of this triple integral is the cabin geometry factor, K. Table 14 lists cabin geometry factors that were calculated by Conners and by this study [Conners: 45]. The numerical algorithm that computed the numbers for this study was checked against examples in Burden and Faires for accuracy [Burden and Faires: 242]. The reason that Conners' numbers differ is not known. This will contribute to differences in cabin ingestion dose values between this study and Conners' study.

Table 14: Cabin Geometry Factors

	Cabin Geometry Factors	
	Computed by Conners	**Computed in This Study**
KC-135:	2.459	4.973
B-1B:	1.395	2.414

Altitude pressure in the aircraft is handled in the following way. Conners mentions that the cabin air is maintained at a pressure equivalent to an 8000 foot altitude when the aircraft is higher than 8000 feet by the aircraft pressurization system. For this reason, the density of 8000-foot air is used in all calculations when an aircraft route is above 8000 feet [Conners: 44].

The dose rate at the center of a simplified spherical volume is given by

$$\dot{D} = (RDDRD)\int_0^R \frac{e^{-\left(\frac{\mu_t}{\rho}\right)_{air}\rho s}}{\cancel{4\pi s^2}}\cancel{4\pi s^2}\,ds \quad \left[\frac{\text{rem}}{\text{hr}}\right] \qquad (31)$$

which can be integrated directly and gives

$$\dot{D} = (RDDRD)\left(\frac{1}{\left(\frac{\mu_t}{\rho}\right)_{air}\rho_{cabin}}\right)\left(1-e^{-\left(\frac{\mu_t}{\rho}\right)_{air}\rho_{cabin}R}\right) \quad \left[\frac{\text{rem}}{\text{hr}}\right] \qquad (32)$$

This simplified model does not require a numerical integration technique to solve. As was the case for sky-shine dose in Equation (20), the spherical model only requires a multiplying factor to convert from redistributed dose rate density to dose rate at the center of the cabin. This is advantageous because the cylindrical model in the FORTRAN program, with the numerical integration algorithm, needs a 2-hour run time to calculate, total dose to aircrew members. The simplified spherical cabin requires just minutes. This model will not be as accurate as a complex modeling scheme, but is sufficient.

Once the dose rate at the center of the cabin is found, the dose at time, t, is given by the following equation.

$$D_t = \dot{D}_{1-hour} \int_{t_a}^{t_a+\Delta t} t^{-1.3} dt \quad [\text{rem}] \tag{33}$$

where t_a is the time of cloud penetration after burst and Δt is the mission duration after cloud penetration. The total dose due to cabin ingestion based on contributions of each cell along the route is the same as was shown in Equation (25).

E. Filtered Cabin Ingestion Dose

One of several ways to prevent exposure to radioactive dust during transit through a nuclear burst cloud is by using air filters, which would allow large particles to be removed from the air that enters the cabin. Smaller particles would pass through. These small particles carry the radioactivity that remains in the cabin for the duration of the mission.

Conners states in his thesis that a filter studied by Rockwell for the B-1 bomber will trap all particles with a radius greater than 10 microns (20 microns in diameter) [Conners: 46]. A filter transmission factor for all groups greater than this size would be

0. None of the particles would be allowed to pass through the filter to contribute dose to the aircrew. Particles between 5 and 10 microns in radius (10-20 microns in diameter) are trapped with 90% efficiency for a filter transmission factor of 0.1. All smaller particles (<10 microns in diameter) pass through with a transmission factor of 1.0 [Conners: 47].

A new hazard poses itself if the filter traps enough dust to create a point source of radioactivity greater than the activity measured in the cabin. This would be a problem for maintenance people. Also, once a filter reaches its limit, the filter is bypassed and unfiltered air enters the cabin. Any calculations involving these phenomena are considered beyond the scope of this study.

Table 15 lists air filter transmission factors that are relevant to the particle groups in HPAC. For a horizontal slice, a user is able to choose which groups to plot and output data for.

Table 15: Air Filter Transmission Factors (B-1B)

B-1B Filter Data

	Particle Size[7] (μm)	Filter Transmission Factor
Group 1	3.54-5.07	1.0
Group 2	5.07-7.27	1.0
Group 3	7.27-10.4	1.0
Group 4	10.4-14.9	0.1
Group 5	14.9-21.4	0.1
Groups 6-20	21.4-4769.5	0.0

To get filtered dose data, Equation (33) is multiplied by the filter transmission factor for each group that will pass through the filter. This will give a total dose for each group. The total doses in each group are then added together to get total filtered dose to the aircrew members.

[7] Particle sizes are diameters, not radii.

Chapter V: Dose Results

A. Input Parameters

Table 16 lists the input parameters that Conners used for his baseline case for his thesis [Conners: 48]. This is the baseline case that is used for comparison in this study. This table lists data for the KC-135 aircraft. The B-1B is also compared here and the only change to Conners' input parameters is the aircraft specification file and aircraft velocity.

Table 16: Conners Baseline Case Input Parameters

```
                 Baseline Case Input Parameters

31 Dec 1438
This is a dose report.
CUSTOM SCENARIO:  Baseline case - DELFIC and KC-135

WEAPON/TARGET DATA:
Number of weapons------------------------- 1
Weapon Yield------------------------------ 1000 KT
Fission Fraction-------------------------- 0.5
Dust Fraction----------------------------- 1/3
The size distribution input file is-------- DELFIC.RMA
                 Rm = .204 : sigma Rm = 4
The soil density is ---------------------- 2600 KG/M3
The aircraft specification file is -------- KC-135.SPC
Aircraft velocity is --------------------- 231.5 M/S
Time from cloud penetration
to end of mission ------------------------ 8 HR
Wind shear X (along track) --------------- 0 (KM/HR)/KM
Wind shear Y (cross track) --------------- 1 (KM/HR)/KM
The output file will be named ------------- A:BASELINE.DOP
```

Inputs into the FORTRAN program, which was developed in this study, are listed in the Subroutines3 module, which is included in Appendix D. The data was chosen to be part of a module instead of an input file for simplicity and because of time constraints.

Appendix D lists the main program along with each module that is necessary to calculate the total dose information that is used to compare with Conners' KC-135, B-1B unfiltered, and B-1B filtered dose results. These three dose result sets encompass aircraft routes for six altitudes and four times after burst. This requires 24 files from HPAC. Also, the first five particle groups (smallest size groups) are used for filtered dose calculation comparison. This adds another 120 data files. In total, 144 HPAC output data files are necessary to complete this comparison.

The Single Route Total Dose FORTRAN program in Appendix D requires only 1 data file for total unfiltered dose calculation with as many data files as is needed for filtered information. This study used the B-1B where only five data files are needed for the first five smallest particle groups. A different aircraft air filter might filter and bypass different particles size groups and those groups would have to be included in the study.

B. Comparison of Results

Tables 18, 19, and 20 show Conners' results for his baseline, second, and third case: KC-135, B-1B without an air filter, and a B-1B with an air filter. These tables are included at the end of this chapter. Tables 21 and 22 show the corresponding HPAC results. Table 22 includes both filtered and non-filtered B-1B results. These tables are results calculated using Conners' cylindrical cabin geometry. The FORTRAN program processes all 144 data files in about two hours. This is a very long run time for calculations such as these. The reason for this is because there are so many data files and the program loops through different subroutines multiple times. The simplified spherical cabin geometry is used to create Tables 23 and 24. The runtime for this version of the program is on the order of a couple of minutes. Also, the simplified spherical cabin

geometry model requires only one extra line of code whereas Conners' cylindrical cabin geometry model requires an extra subroutine to compute the numerical double integration as was explained in Chapter IV, and is shown in Module Subroutines11 in Appendix D. Figures 32 through 39 show these dose results graphically.

Comparing the cylindrical geometry results, Conners' results are higher by, at most, a couple of rem at earlier times except at 10000 and 8000 meters where the HPAC results are greater, still only by, at most, a couple of rem. As time after burst increases, the HPAC results shift to be greater than Conners' results. This could suggest that the particles remain in the cloud longer in HPAC than those of the smearing model. Also, wind shear effects could be a slight contributing factor for higher HPAC results at later times.

Conners uses a wind shear of 0 $\frac{km/hr}{km}$ in the along track (X) direction and 1 $\frac{km/hr}{km}$ in the cross track (Y) direction. A constant wind shear was not directly implemented in HPAC because the SCIPUFF documentation stated that it accurately models wind shear [DTRA, 2000: Overview of SCIPUFF]. However, it is not known exactly how SCIPUFF handles wind shear. As was stated in Chapter I, Section C, a zero m/s constant wind was entered into the Weather option in HPAC.

Conners chose the aircraft penetration direction to be in the X-direction. For the HPAC data, the aircraft starts at one side of the cloud and flies straight through the center to the other side. Because of the zero winds option that was chosen, the cloud layer is symmetric around ground zero and it doesn't matter at what direction the aircraft enters from, the aircraft will sweep out the same total dose at any angle. This is not true for

Conners' data. With the wind shears mentioned above, and with an aircraft route in the X-direction, the aircraft will be flying through a slightly widened cloud because of the cross track wind shear. The aircrew will absorb slightly less total dose while flying through this cloud than a cloud with no directly implemented wind shear, because the radioactivity is spread thinner throughout the cloud. If the magnitude of the X-direction wind shear is increased and the magnitude of the Y-direction wind shear remains constant, the aircraft will experience the same total dose. The cloud is longer, but the aircraft will still fly through the length of the cloud, thus sweeping out the same amount of radioactivity.

So, in effect, the HPAC cloud remains symmetric at every time after burst, but Conners' cloud is thinning out as time after burst increases due to cross track wind shear. As was mentioned above, it is not known exactly what SCIPUFF does to handle wind shear. To fully understand wind shear in HPAC is beyond the scope of this research.

When HPAC uses the simplified spherical model, the results at 12000 meters are about half of what Conner' calculates. The remaining results are within, at most, a couple of rem of each other. For the cylindrical model, the results had the greatest difference at 12000 meters also. Because the spherical geometry is much simpler, it further adds to the difference. Still, the difference is on the order of a few rem which means that the simplified spherical model could be used if program runtime is a concern without much cost in accuracy.

A Number of Data Points study was conducted in order to find out how many data points needed to be used in the data files in order to get accurate total dose results. Tables 25 and 26 show results of this study. These results were calculated using the

FORTRAN program in Appendix D. This program is the tool that was developed in this study for single aircraft routes through a nuclear cloud and could be used by USSTRATCOM to calculate total dose to aircrew members at a certain altitude. The Number of Data Points study was conducted in order to find out how many data points needed to be used in the data files in order to get accurate total dose results. For the comparison to Conners' data, 30,000 data points were used and each of the 144 data files was about 1.3 Mbytes in size. This is another major reason why the comparison program took so long to run with Conners' cylindrical cabin geometry.

These tables show results using the B-1B aircraft data. This aircraft was chosen so that filtered and un-filtered results could be calculated. Table 25 shows that no change in the third decimal place took place. The precision in output was increased in order to find out where total dose changed and this is shown in Table 26. This table only shows changes in the fourth decimal place, even when the number of data points is changed from 30,000 to 100. The data file size would decrease from 1.3 Mbytes to about 5 Kbytes. The results of the Number of Data Points study suggest that significantly smaller data files could be used to get virtually the same total dose results. This would decrease the overall runtime of HPAC (to output the data files) and of the FORTRAN Dose Calculation programs. Total runtime for a 100-point data file aircraft route would be less than a minute, even with complex cabin geometry (cylindrical in this case).

Because the greatest total dose result is about 10 rem, relatively minor or no immediate health effects would occur to the aircrew. Eisenbud lists a summary of clinical effects of acute ionizing radiation doses in his Table 2-1 [Eisenbud: 16, 17]. Based on the information in this table (where 1 rad equals 1 rem for gamma radiation in

tissue), the results calculated by this study, and by Conners, would suggest that an aircrew would be able to make it back to base, in a healthy state, after having flown through a 1 megaton burst with a fission fraction of 0.5 and an 8 hour mission duration at 1 hour after burst.

Table 17: Conners' Baseline Case: DELFIC Cloud and KC-135

Conners Baseline Case: DELFIC Cloud and KC-135			
1-hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Dust (rem)**	**Total Dose (rem)**
12000	6.720	3.620	10.340
10000	3.190	1.710	4.900
8000	1.460	0.790	2.250
6000	0.817	0.440	1.257
4000	0.511	0.275	0.786
2000	0.335	0.180	0.515
2-hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Dust (rem)**	**Total Dose (rem)**
12000	1.730	1.440	3.170
10000	0.842	0.702	1.544
8000	0.399	0.332	0.731
6000	0.236	0.196	0.432
4000	0.160	0.133	0.293
2000	0.112	0.093	0.205
4-hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Dust (rem)**	**Total Dose (rem)**
12000	0.404	0.482	0.886
10000	0.200	0.240	0.440
8000	0.097	0.116	0.213
6000	0.058	0.069	0.127
4000	0.038	0.046	0.084
2000	0.028	0.033	0.061
8-hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Dust (rem)**	**Total Dose (rem)**
12000	0.083	0.130	0.213
10000	0.042	0.067	0.109
8000	0.021	0.033	0.054
6000	0.012	0.019	0.031
4000	0.009	0.013	0.022
2000	0.006	0.010	0.016

Table 18: Conners' Second Case: DELFIC Cloud and B-1B Without Air Filter

Conners Baseline Case: DELFIC Cloud and B-1B Without Air Filter			
1-hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Dust (rem)**	**Total Dose (rem)**
12000	4.160	4.770	8.930
10000	1.970	2.260	4.230
8000	0.909	1.040	1.949
6000	0.506	0.580	1.086
4000	0.316	0.362	0.678
2000	0.207	0.237	0.444
2-hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Dust (rem)**	**Total Dose (rem)**
12000	1.070	1.900	2.970
10000	0.521	0.925	1.446
8000	0.247	0.438	0.685
6000	0.146	0.259	0.405
4000	0.099	0.176	0.275
2000	0.069	0.123	0.192
4-hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Dust (rem)**	**Total Dose (rem)**
12000	0.250	0.636	0.886
10000	0.124	0.316	0.440
8000	0.060	0.154	0.214
6000	0.035	0.091	0.126
4000	0.024	0.061	0.085
2000	0.017	0.044	0.061
8-hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Dust (rem)**	**Total Dose (rem)**
12000	0.051	0.172	0.223
10000	0.026	0.088	0.114
8000	0.013	0.043	0.056
6000	0.008	0.026	0.034
4000	0.005	0.017	0.022
2000	0.004	0.012	0.016

Table 19: Conners' Third Case: DELFIC Cloud and B-1B With Air Filter

Conners Baseline Case: DELFIC Cloud and B-1B With Air Filter			
1-hour			
Altitude (m)	**Cabin Dust (rem)**	**Sky Shine (rem)**	**Total Dose (rem)**
12000	0.850	4.160	5.010
10000	0.166	1.970	2.136
8000	0.011	0.909	0.920
6000	0.000	0.506	0.506
4000	0.000	0.316	0.316
2000	0.000	0.207	0.207
2-hour			
Altitude (m)	**Cabin Dust (rem)**	**Sky Shine (rem)**	**Total Dose (rem)**
12000	0.408	1.070	1.478
10000	0.080	0.521	0.601
8000	0.006	0.247	0.253
6000	0.000	0.146	0.146
4000	0.000	0.099	0.099
2000	0.000	0.069	0.069
4-hour			
Altitude (m)	**Cabin Dust (rem)**	**Sky Shine (rem)**	**Total Dose (rem)**
12000	0.167	0.250	0.417
10000	0.033	0.124	0.157
8000	0.003	0.060	0.063
6000	0.000	0.035	0.035
4000	0.000	0.024	0.024
2000	0.000	0.017	0.017
8-hour			
Altitude (m)	**Cabin Dust (rem)**	**Sky Shine (rem)**	**Total Dose (rem)**
12000	0.056	0.051	0.107
10000	0.012	0.026	0.038
8000	0.001	0.013	0.014
6000	0.000	0.008	0.008
4000	0.000	0.005	0.005
2000	0.000	0.004	0.004

Table 20: HPAC KC-135 Dose (Cylindrical Cabin Model)

KC135 Dose (Cylindrical Cabin Model)			
1 hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (rem)**	**Total Dose (rem)**
12000	4.312	3.993	8.305
10000	3.428	3.174	6.601
8000	1.407	1.303	2.71
6000	0.577	0.535	1.112
4000	0.415	0.384	0.799
2000	0.258	0.239	0.497
2 hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (rem)**	**Total Dose (rem)**
12000	0.975	1.433	2.408
10000	0.798	1.172	1.97
8000	0.347	0.51	0.856
6000	0.151	0.222	0.374
4000	0.099	0.146	0.245
2000	0.069	0.101	0.169
4 hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (rem)**	**Total Dose (rem)**
12000	0.276	0.594	0.869
10000	0.227	0.489	0.715
8000	0.113	0.243	0.356
6000	0.047	0.1	0.147
4000	0.031	0.066	0.097
2000	0.025	0.054	0.079
8 hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (rem)**	**Total Dose (rem)**
12000	0.049	0.141	0.19
10000	0.044	0.127	0.171
8000	0.022	0.062	0.084
6000	0.01	0.028	0.038
4000	0.005	0.016	0.021
2000	0.005	0.013	0.018

Table 21: HPAC B-1B Dose (Cylindrical Cabin Model)

B-1B Dose (Cylindrical Cabin Model, rem)					
1 hour					
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (CI) (rem)**	**Filtered CI (rem)**	**Total Un-Filtered (rem)**	**Total Filtered (rem)**
12000	2.673	4.475	0.986	7.148	3.659
10000	2.125	3.556	0.772	5.681	2.896
8000	0.872	1.46	0.037	2.333	0.909
6000	0.358	0.599	0	0.957	0.358
4000	0.257	0.43	0	0.688	0.257
2000	0.16	0.268	0	0.428	0.16
2 hour					
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (CI) (rem)**	**Filtered CI (rem)**	**Total Un-Filtered (rem)**	**Total Filtered (rem)**
12000	0.604	1.605	0.425	2.21	1.029
10000	0.494	1.313	0.329	1.808	0.823
8000	0.215	0.571	0.018	0.786	0.233
6000	0.094	0.249	0	0.343	0.094
4000	0.062	0.164	0	0.225	0.062
2000	0.042	0.113	0	0.155	0.042
4 hour					
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (CI) (rem)**	**Filtered CI (rem)**	**Total Un-Filtered (rem)**	**Total Filtered (rem)**
12000	0.171	0.665	0.219	0.836	0.39
10000	0.141	0.548	0.166	0.688	0.306
8000	0.07	0.273	0.284	0.343	0.354
6000	0.029	0.112	0	0.141	0.029
4000	0.019	0.074	0	0.093	0.019
2000	0.016	0.06	0	0.076	0.016
8 hour					
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (CI) (rem)**	**Filtered CI (rem)**	**Total Un-Filtered (rem)**	**Total Filtered (rem)**
12000	0.03	0.158	0.063	0.188	0.093
10000	0.027	0.142	0.048	0.169	0.075
8000	0.013	0.07	0.005	0.083	0.019
6000	0.006	0.032	0	0.038	0.006
4000	0.003	0.017	0	0.021	0.003
2000	0.003	0.015	0	0.018	0.003

Table 22: HPAC KC-135 Dose (Spherical Cabin Model)

KC-135 Dose (Spherical Cabin Model)			
1 hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (rem)**	**Total (rem)**
12000	4.312	1.428	5.74
10000	3.428	1.135	4.563
8000	1.407	0.466	1.873
6000	0.577	0.191	0.769
4000	0.415	0.137	0.552
2000	0.258	0.086	0.344
2 hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (rem)**	**Total (rem)**
12000	0.975	0.512	1.487
10000	0.798	0.419	1.217
8000	0.347	0.182	0.529
6000	0.151	0.08	0.231
4000	0.099	0.052	0.152
2000	0.069	0.036	0.105
4 hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (rem)**	**Total (rem)**
12000	0.276	0.212	0.488
10000	0.227	0.175	0.402
8000	0.113	0.087	0.2
6000	0.047	0.036	0.082
4000	0.031	0.024	0.055
2000	0.025	0.019	0.044
8 hour			
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (rem)**	**Total (rem)**
12000	0.049	0.05	0.099
10000	0.044	0.045	0.089
8000	0.022	0.022	0.044
6000	0.01	0.01	0.02
4000	0.005	0.006	0.011
2000	0.005	0.005	0.009

Table 23: HPAC B-1B Dose (Spherical Cabin Model)

B-1B Dose (Spherical Cabin Model)					
1 hour					
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (CI) (rem)**	**Filtered CI (rem)**	**Total Un-Filtered (rem)**	**Total Filtered (rem)**
12000	2.673	1.979	0.436	4.652	3.109
10000	2.125	1.573	0.341	3.697	2.466
8000	0.872	0.646	0.016	1.518	0.889
6000	0.358	0.265	0	0.623	0.358
4000	0.257	0.19	0	0.447	0.257
2000	0.16	0.119	0	0.279	0.16
2 hour					
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (CI) (rem)**	**Filtered CI (rem)**	**Total Un-Filtered (rem)**	**Total Filtered (rem)**
12000	0.604	0.71	0.188	1.314	0.792
10000	0.494	0.581	0.145	1.075	0.64
8000	0.215	0.253	0.008	0.468	0.223
6000	0.094	0.11	0	0.204	0.094
4000	0.062	0.072	0	0.134	0.062
2000	0.042	0.05	0	0.092	0.042
4 hour					
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (CI) (rem)**	**Filtered CI (rem)**	**Total Un-Filtered (rem)**	**Total Filtered (rem)**
12000	0.171	0.294	0.097	0.465	0.268
10000	0.141	0.242	0.073	0.383	0.214
8000	0.07	0.121	0.126	0.191	0.196
6000	0.029	0.05	0	0.079	0.029
4000	0.019	0.033	0	0.052	0.019
2000	0.016	0.027	0	0.042	0.016
8 hour					
Altitude (m)	**Sky Shine (rem)**	**Cabin Ingestion (CI) (rem)**	**Filtered CI (rem)**	**Total Un-Filtered (rem)**	**Total Filtered (rem)**
12000	0.03	0.07	0.028	0.1	0.058
10000	0.027	0.063	0.021	0.09	0.048
8000	0.013	0.031	0.002	0.044	0.016
6000	0.006	0.014	0	0.02	0.006
4000	0.003	0.008	0	0.011	0.003
2000	0.003	0.007	0	0.01	0.003

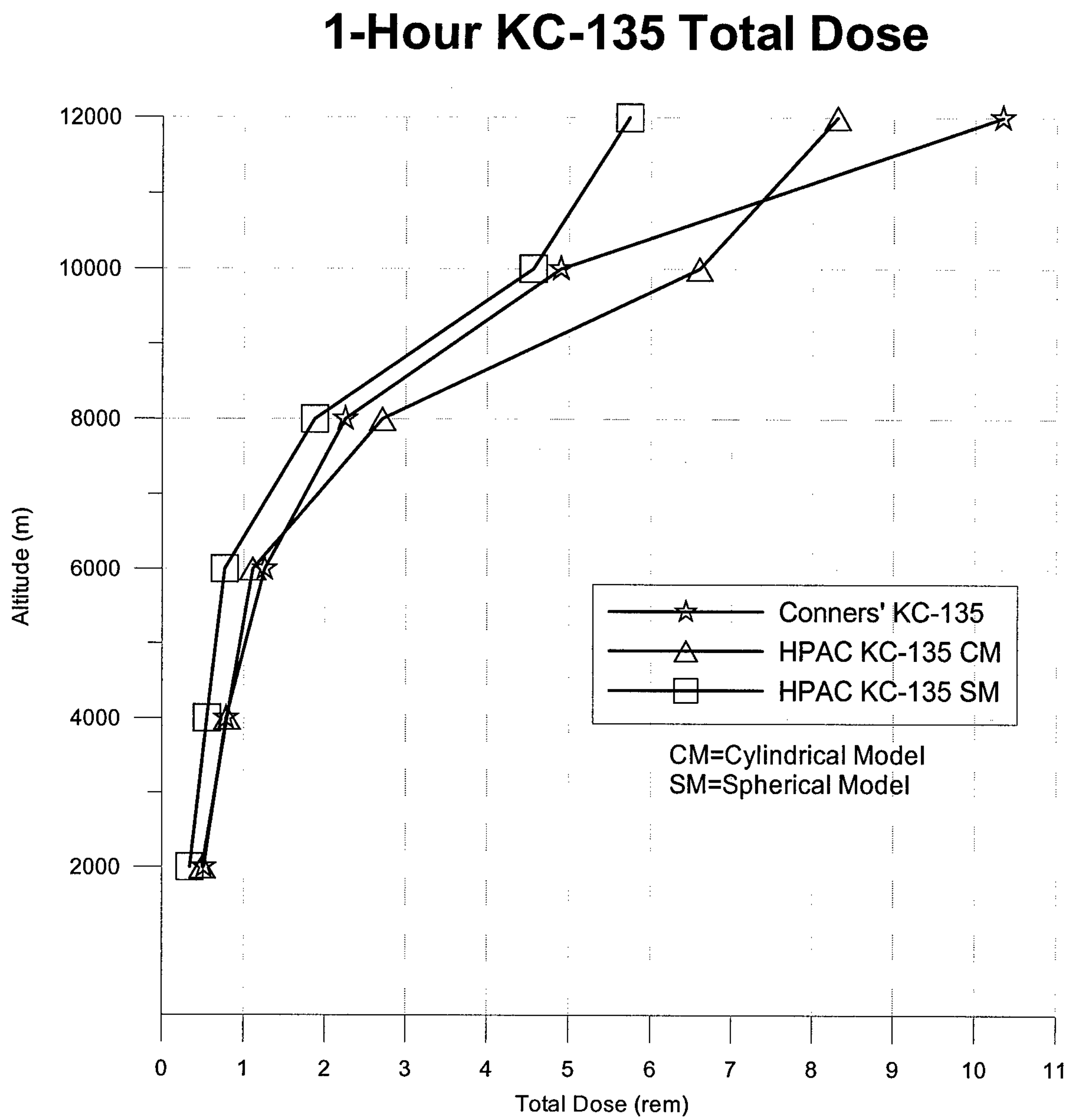

Figure 32: 1-Hour KC-135 Total Dose Data

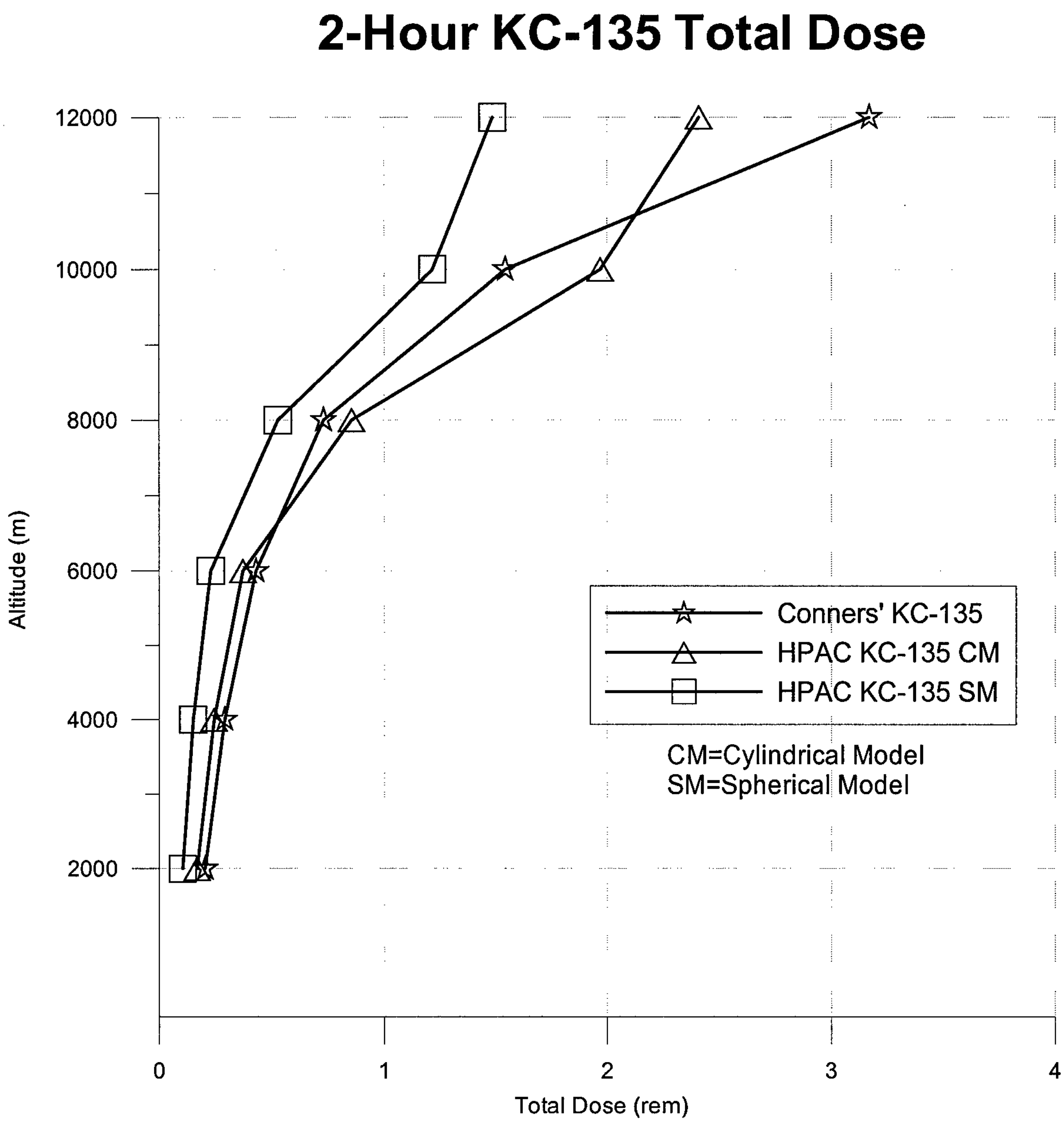

Figure 33: 2-Hour KC-135 Total Dose Data

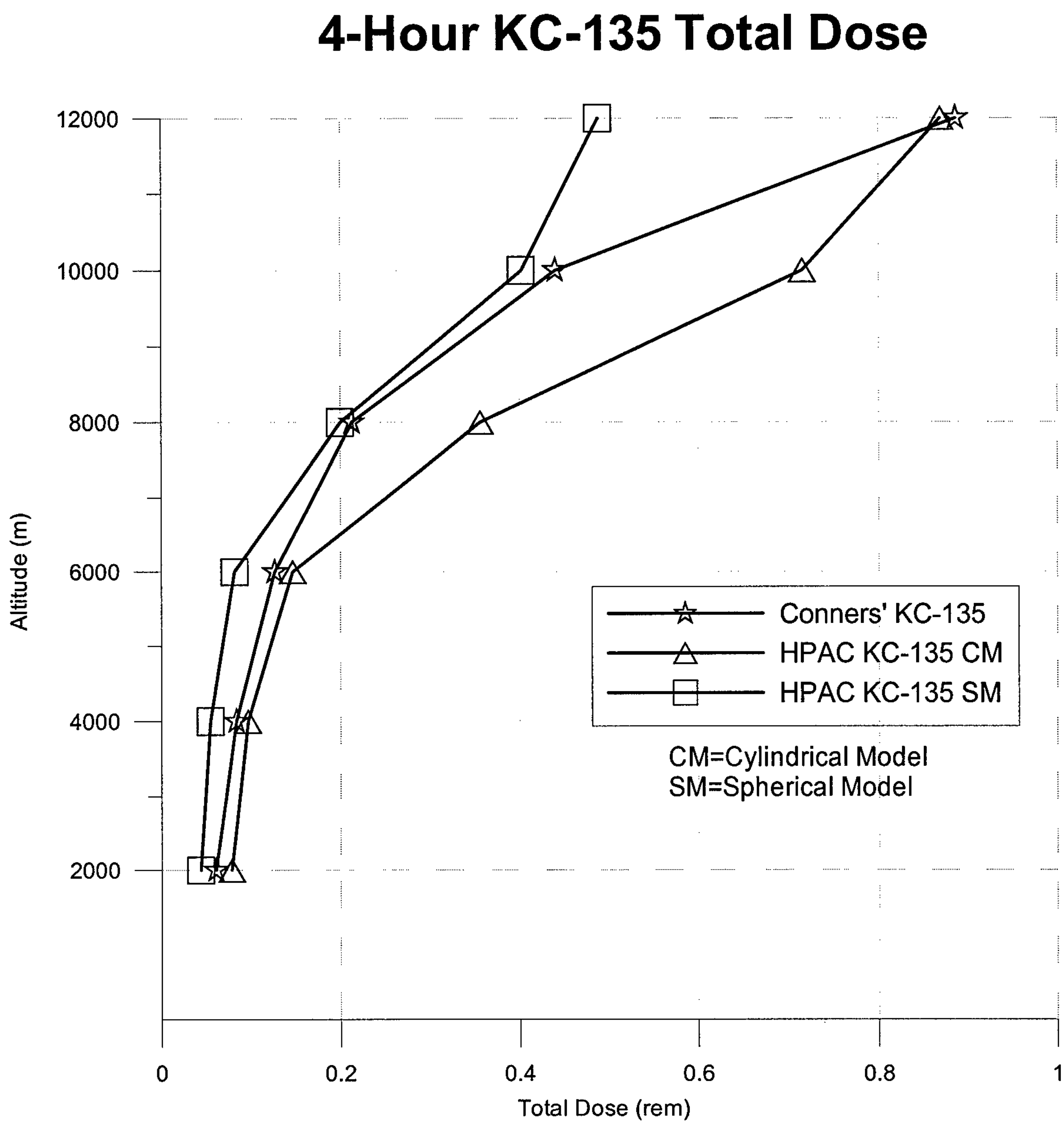

Figure 34: 4-Hour KC-135 Total Dose Data

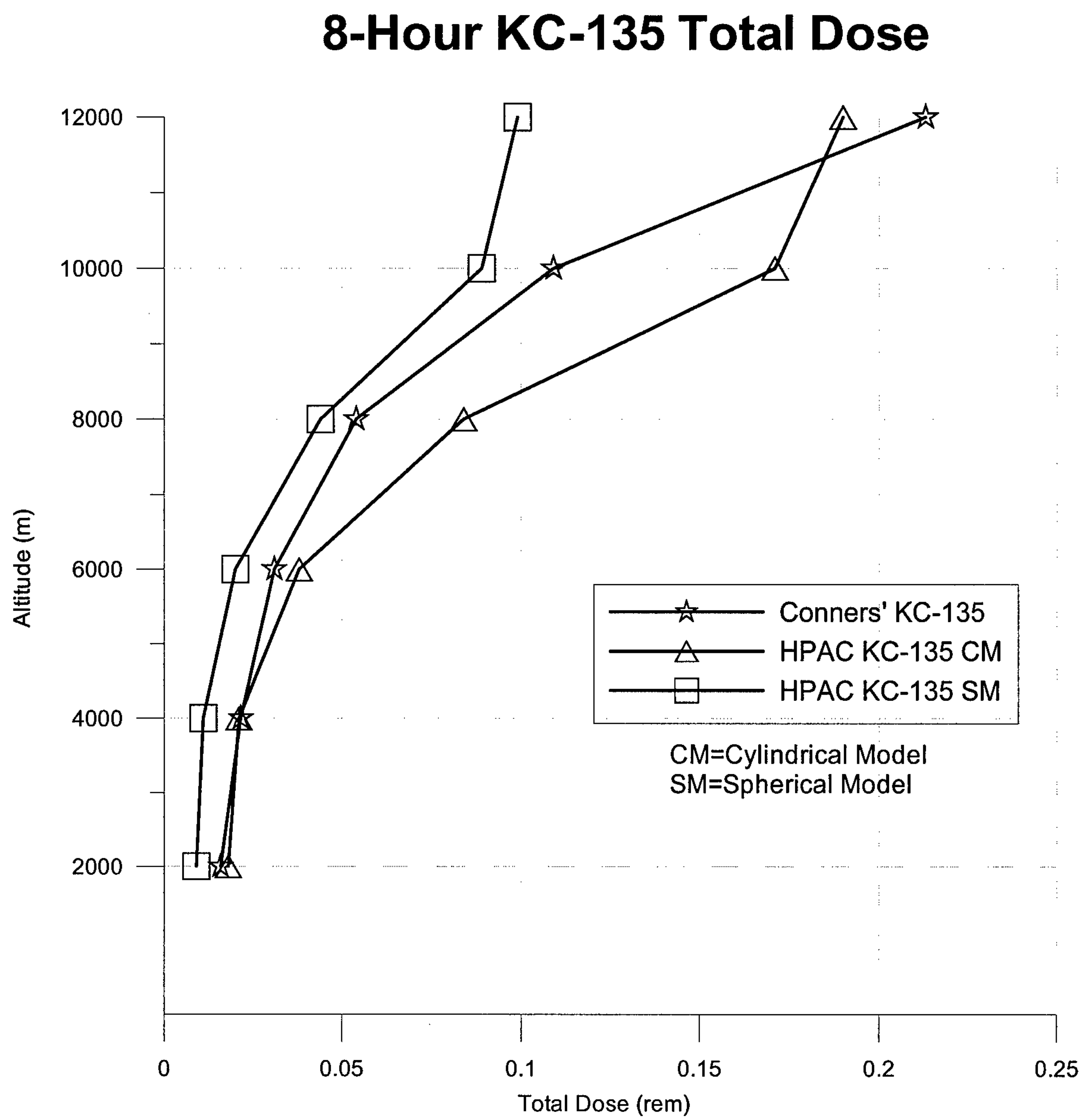

Figure 35: 8-Hour KC-135 Total Dose Data

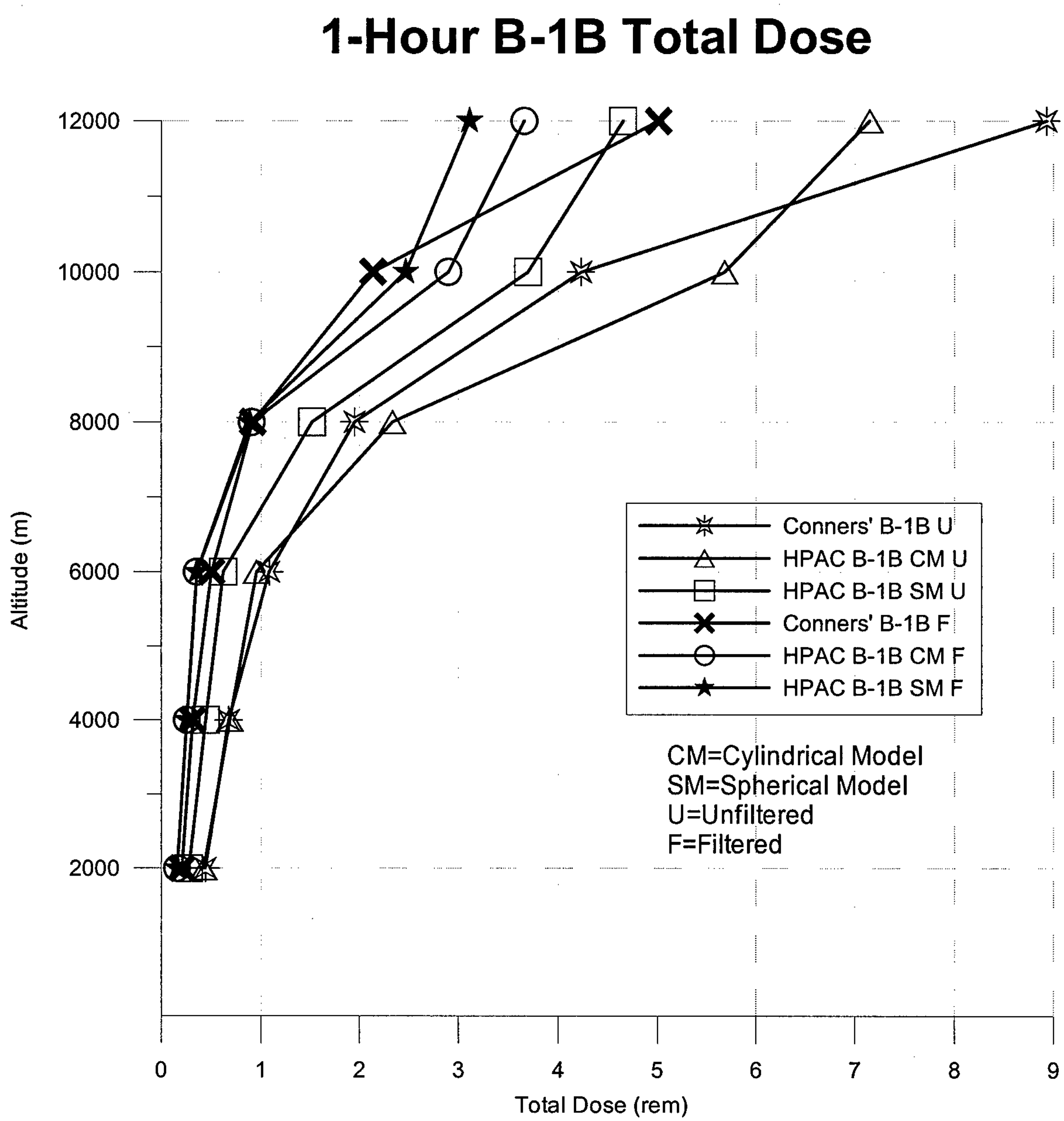

Figure 36: 1-Hour B-1B Total Dose Data

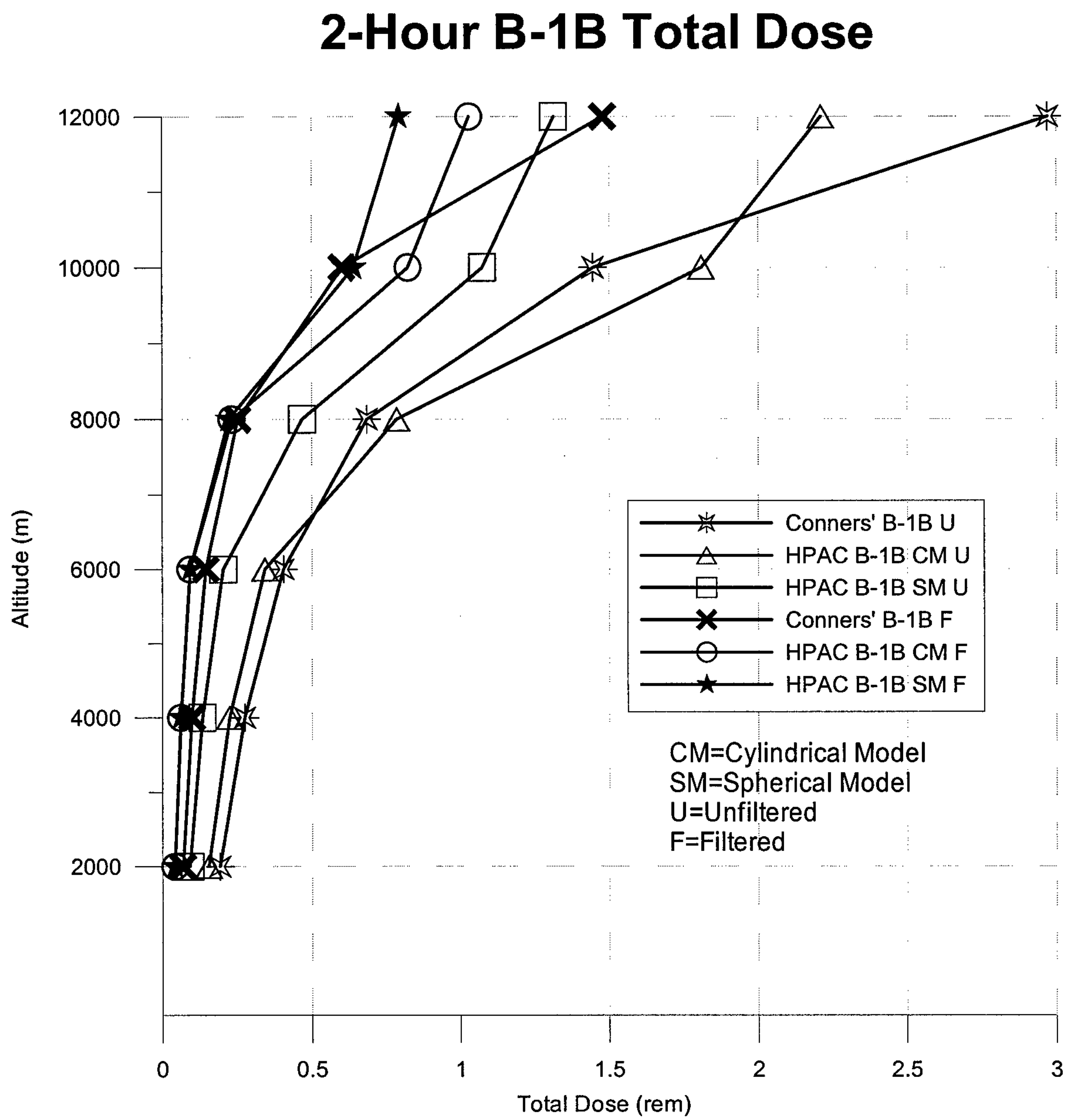

Figure 37: 2-Hour B-1B Total Dose Data

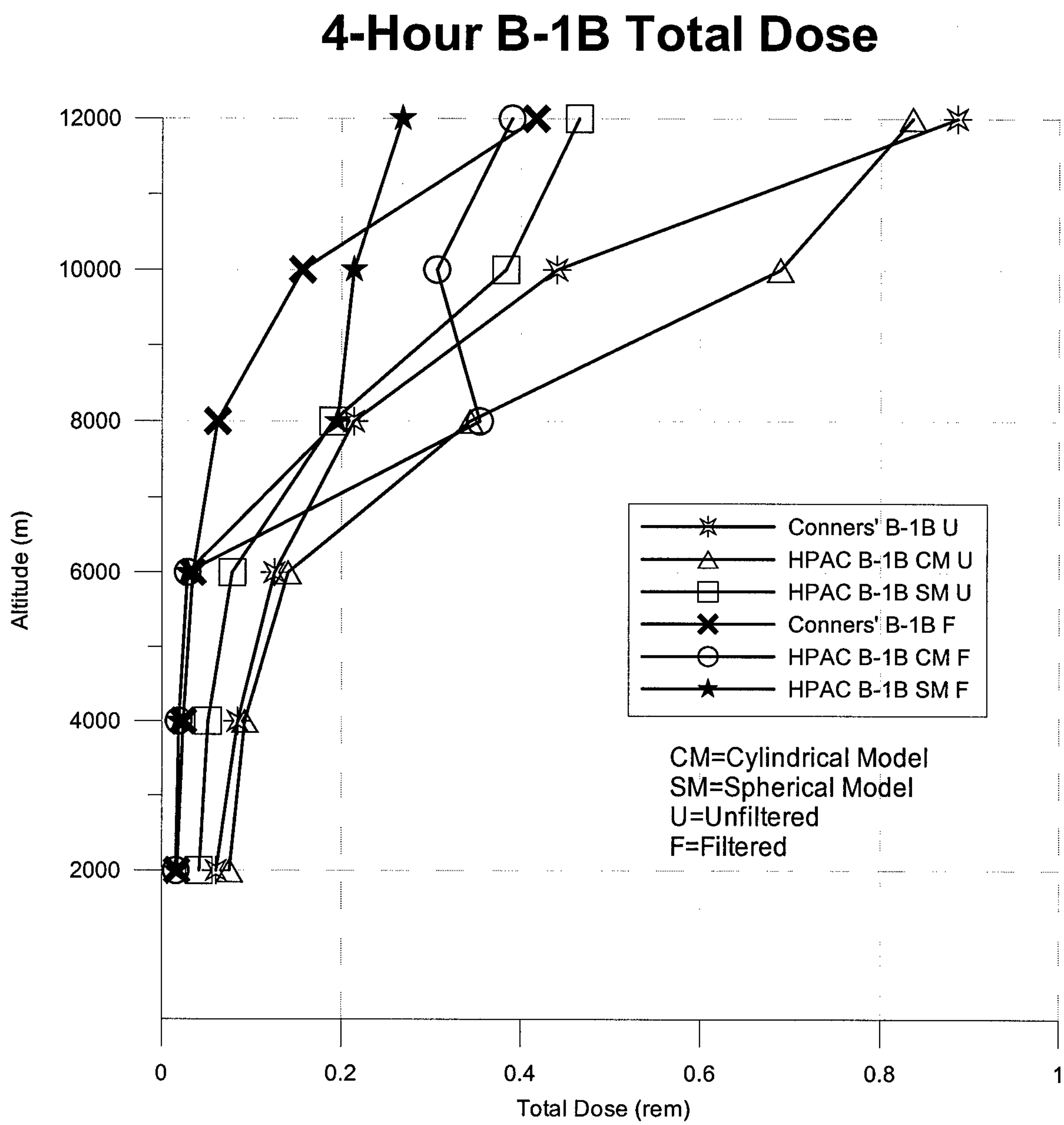

Figure 38: 4-Hour B-1B Total Dose Data

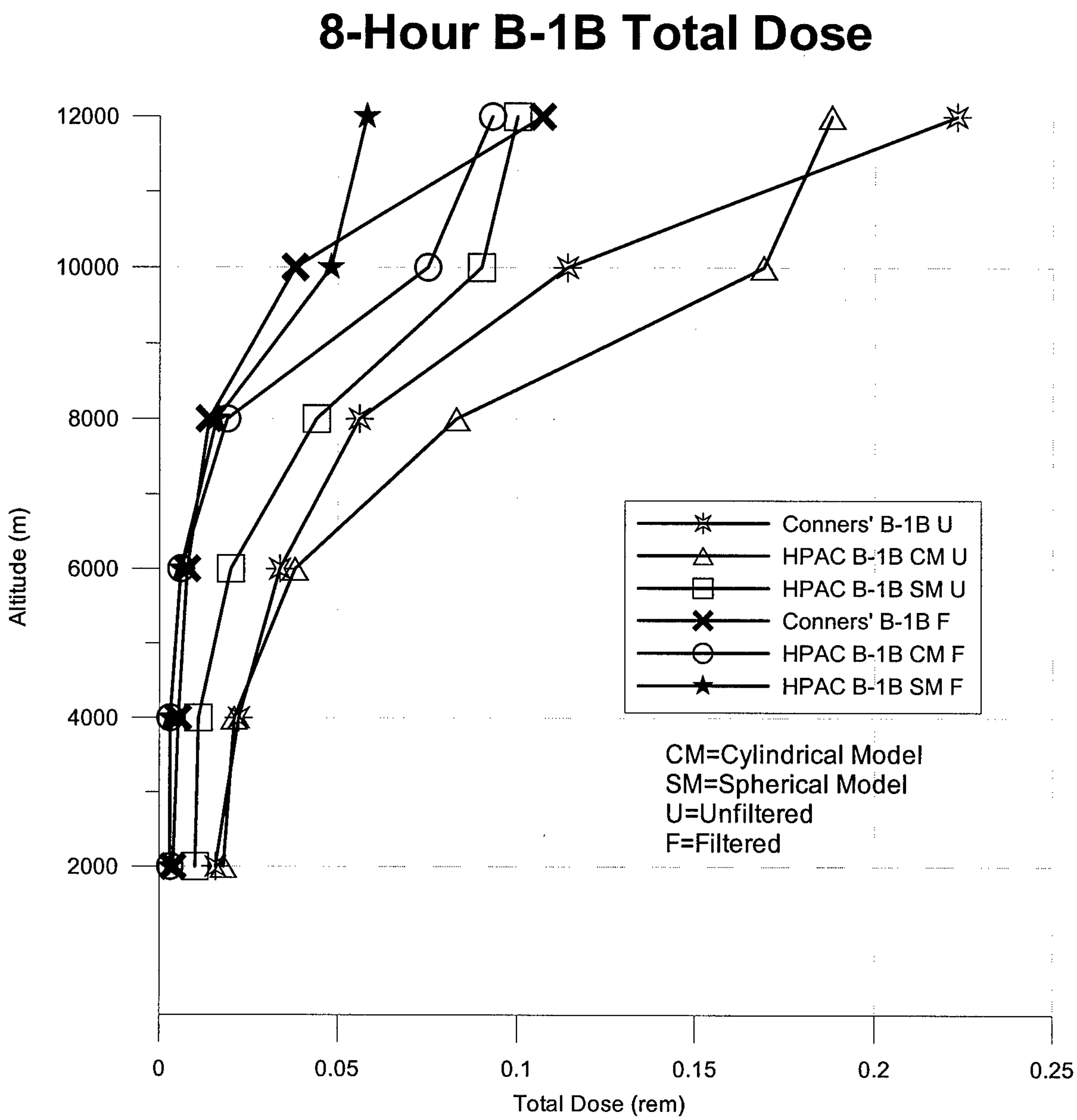

Figure 39: 8-Hour B-1B Total Dose Data

Table 24: B-1B Dose -- Number of Data Points Study

B1B Dose -- Number of Data Points Study (Dose in rem)

30000 Data Points

4 hour

Altitude (m)	Sky Shine Dose	Cabin Ingestion (CI) Dose	Filtered CI Dose	Total Un-Filtered Dose	Total Filtered Dose
10000	0.144	0.248	0.075	0.392	0.219

25000 Data Points

4 hour

Altitude (m)	Sky Shine Dose	Cabin Ingestion (CI) Dose	Filtered CI Dose	Total Un-Filtered Dose	Total Filtered Dose
10000	0.144	0.248	0.075	0.392	0.219

20000 Data Points

4 hour

Altitude (m)	Sky Shine Dose	Cabin Ingestion (CI) Dose	Filtered CI Dose	Total Un-Filtered Dose	Total Filtered Dose
10000	0.144	0.248	0.075	0.392	0.219

15000 Data Points

4 hour

Altitude (m)	Sky Shine Dose	Cabin Ingestion (CI) Dose	Filtered CI Dose	Total Un-Filtered Dose	Total Filtered Dose
10000	0.144	0.248	0.075	0.392	0.219

10000 Data Points

4 hour

Altitude (m)	Sky Shine Dose	Cabin Ingestion (CI) Dose	Filtered CI Dose	Total Un-Filtered Dose	Total Filtered Dose
10000	0.144	0.248	0.075	0.392	0.219

5000 Data Points

4 hour

Altitude (m)	Sky Shine Dose	Cabin Ingestion (CI) Dose	Filtered CI Dose	Total Un-Filtered Dose	Total Filtered Dose
10000	0.144	0.248	0.075	0.392	0.219

1000 Data Points

4 hour

Altitude (m)	Sky Shine Dose	Cabin Ingestion (CI) Dose	Filtered CI Dose	Total Un-Filtered Dose	Total Filtered Dose
10000	0.144	0.248	0.075	0.392	0.219

Table 25: B-1B Dose -- Number of Data Points Study (Increased Precision)

B1B Dose -- Number of Data Points Study (Increase Precision, Dose in Rem)					
30000 Data Points					
4 hour					
Altitude (m)	**Sky Shine Dose**	**Cabin Ingestion (CI) Dose**	**Filtered CI Dose**	**Total Un-Filtered Dose**	**Total Filtered Dose**
10000	0.1439	0.2479	0.0746	0.3918	0.2186
1000 Data Points					
4 hour					
Altitude (m)	**Sky Shine Dose**	**Cabin Ingestion (CI) Dose**	**Filtered CI Dose**	**Total Un-Filtered Dose**	**Total Filtered Dose**
10000	0.1439	0.2479	0.0746	0.3918	0.2186
100 Data Points					
4 hour					
Altitude (m)	**Sky Shine Dose**	**Cabin Ingestion (CI) Dose**	**Filtered CI Dose**	**Total Un-Filtered Dose**	**Total Filtered Dose**
10000	0.1439	0.2478	0.0746	0.3917	0.2185

Chapter VI: Conclusions and Recommendations

A. Conclusions

This study has developed a FORTRAN program that uses HPAC output of radioactive cloud environments that it generates. This program takes the output data files from HPAC, which are based on certain input parameters defined by the user, and processes them to calculate sky-shine and cabin ingestion doses. Both filtered and un-filtered cabin ingestion dose is calculated. B-1B aircraft air filter data is used to determine which particle groups are used from HPAC. It was found that the first five smallest groups get passed through the filter into the cabin and contribute radiation dose to the aircrew. If different aircraft were used, the air filter data for that aircraft engine would have to be studied in order to determine which particle groups get used from HPAC.

The first version of the FORTRAN program used HPAC output data files necessary to compare with Conners' calculated dose results. The HPAC results, calculated by the FORTRAN program, compare very well with Conners' results with the greatest difference in total dose being on the order of a few rem. Conners' biggest total dose value was about 10 rem and total dose from HPAC was about 8 rem. The average percent difference between Conners' results and the results from this study is 23.4%. This percent difference is big, but remember it represents differences at most of a couple of rem because the total dose values were small to begin with. This total absorbed acute dose will not affect the aircrew significantly health wise as well as any positive or negative fluctuations of a couple of rem. The crew can make it back to base having completed their mission. Also, much higher doses (approaching 150 rem) would be

tolerable so aircraft dose from even a megaton size weapon isn't the main problem faced by the aircrew. Other damage mechanisms will be more harmful than the radiation dose they receive.

The FORTRAN program, which calculated total dose results that were compared to Conners' results, took about two hours to run. This program used data files that were about 1.3 Mbytes in size and included 30,000 data points. Also, with Conners' cylindrical cabin geometry, the program requires an extra module to compute the numerical integrals necessary for this geometry. This study found that the results do not differ significantly when a simplified spherical cabin geometry is used, which does not require an extra module but a single line of code, and when the data file number of data points is decreased to 100 from 30,000. This decreases runtime from about two hours to less than a minute.

The Single Route FORTRAN program, that was developed as the tool that USSTRATCOM can use, required 6 data files for total filtered and un-filtered dose. Even with 30,000 data points and the complex cylindrical cabin geometry, the code ran in about a minute. This is significantly less than the hour it currently takes USSTRATCOM to run the Excel file macro that calculates their total dose. This program can be modified and adapted for different cabin geometries and aircraft data including velocity, mass, mass airflow rates, etc.

B. Recommendations

There are a few recommendations, as a result of this study, to be made. First, the transitions from 50 particle groups to 20, when NewFall hands off puff information to SCIPUFF, could be studied to better understand how the re-grouping takes place. There

are missing particle groups in the puff information fields in the NEWTRANS.OUT file and the activity distribution around those missing groups is still a mystery.

The transport of particles by SCIPUFF could be studied to see how exactly different the puff model is compared to the smearing and disk-tosser models. SCIPUFF uses Gaussian puffs that get split and merged while smearing codes use Gaussian distributions. It would be interesting to fully understand the differences between the two.

Another recommendation is to study how SCIPUFF handles wind shear. It is not currently known how wind shear is handled in HPAC. The only option for entering a constant wind was the Fixed Wind option in the Weather Editor which does not seem to account for wind shear.

Lastly, the FORTRAN program could be altered to include a wider range of aircraft and scenario specification inputs instead of having those inputs directly hard-wired into the program. The robustness could be improved, but knowledge of the details of the aircraft and scenarios in question would have to be learned in order to accomplish this.

Appendix A: 100 Group Volumetric Particle Distribution

This appendix describes a FORTRAN code written by this author that creates a 100-group, equal activity, particle distribution based on a cumulative lognormal. The code assumes a 100% volumetrically distributed particle distribution with a mean radius of 0.2 μm and a geometric standard deviation of 4.0. This gives an $\alpha_0 = \ln(0.2)$, a $\beta = \ln(4.0)$, and an $\alpha 3 = \alpha_0 + 3\beta^2$. The code calculates the distribution by increasing the particle radius by a very small amount until it reaches the desired cumulative percentage. For this case of 100 particle groups, each group represents 1.0% of the total activity. So for a cumulative distribution, the last group would have 100% of the total activity. This code finds the mean radius of the particle group (not the boundaries of the groups) by finding the radius at each half percentage. For example, the first radius is found at the 0.5%, the next at 1.5%, and so on up until the code reaches 99.5%. Thus, 0%, 1%, ... 99%, and 100% would be particle group boundaries.

This particle distribution code was created as part of a smearing code written as an assignment for a class at AFIT. It is included in this thesis to serve as a comparison to the distributions that are used in HPAC. This code was written using Compaq Visual FORTRAN Professional Edition 6.1.0. There is a very short main program that calls a subroutine called ParticalDistribution. This subroutine is in a module called MYSubroutines. This module contains ParticalDistribution and ActVolCumNorm. ActVolCumNorm is the subroutine that calculates the volumetric cumulative normal function value, which gets reported back to ParticalDistribution. The output file is called Rg.txt and includes the particle radius and cumulative fraction of total activity.

A. Main Program

```
Program ParticleDistribution

Use MYsubroutines

! 11/04/2000 (FEG)

Implicit None

Real(8), Dimension(100,2) :: Rg  ! Particle Distribution Array
        !100-groups that include both particle radius and
        !cumulative probability (percent of total activity)

Call ParticalDistribution(Rg)


End Program ParticleDistribution
```

B. Module

```
Module MYsubroutines
Implicit None

!This module contains the volumetrically distributed cumulative
!normal function and the subroutine that finds the particle
!cumulative normal distribution based on equal activity per
!particle group volumetrically distributed.

Contains

!------Activity Volumetrically Distributed Cumulative Normal-------------

!Sub that contains calculations for the Cumulative Normal Function:
        Subroutine ActVolCumNorm (Fofx, r)
        Implicit None

        !Output Variables
        Real(8), Intent(Out)::Fofx
        !Input Variables
        Real(8), Intent(IN) :: r

        ! Local Variables
        Real(8) :: Bursttype
```

```
        Real(8) :: Alpha
        Real(8) :: Beta
        Real(8) :: x, x2

                        Alpha=Log(0.2)
                        Beta=Log(4.0)
                        Alpha=Alpha+3*Beta**2

        x=(Log(r)-Alpha)/Beta
        x2=Abs(x)

        Fofx=1.0-0.5*(1.0+0.196854*x2+0.115194*x2**2+&
            &0.000344*x2**3.0+0.019527*x2**4)**(-4)

        If (x<0) Then
                        Fofx=1-Fofx
            Else
                        Fofx=Fofx
        End If

        End Subroutine ActVolCumNorm

!-------Subroutine engine to get radii for 100 group distribution--------
Subroutine ParticalDistribution(Rg)
! Output Variable
Real(8), Intent(OUT), Dimension(100,2) :: Rg

!Local Variables
Real(8) :: Fofx
Real(8) :: r
Real(8) :: Fraction !output from Cum Normal

Integer :: gnumber !  radius group number

Open (Unit=10, Status="unknown", File="Rg.txt")

gnumber=1
Rg(1,1)=.001   ! Assume an initial radius {microns}
                                ! :1 is for Radius and :2 is for Fraction
Fraction=0.005          ! Radius steps up until Fofx reaches Fraction value
r=Rg(1,1)
        Do While (Fraction<0.996)
            Call ActVolCumNorm(Fofx,r)
            If (Fofx<Fraction) Then
                r=1.001*r
                Else
```

```
                        Rg(gnumber,1)=r
                        Rg(gnumber,2)=Fofx
                        !Print *, Rg(gnumber,1), Rg(gnumber,2)
                        Write (10,*)Rg(gnumber,1),Rg(gnumber,2)
                        gnumber=gnumber+1
                        Fraction=Fraction+0.01
                End If
        End Do
End Subroutine ParticalDistribution
!------------------------------------------------------------------

End Module Mysubroutines
```

C. Output File: Rg.txt

Table 26 shows the contents of Rg.txt. The numbers have been formatted using Excel to fit into this table.

Table 26: 100-Group Equal Activity Volumetric Particle Size Distribution

Group #	Mean Radius (μm)	Activity Fraction	Group #	Mean Radius (μm)	Activity Fraction
1	1.76625	0.00500	51	64.98929	0.50518
2	3.16323	0.01502	52	67.30313	0.51516
3	4.23956	0.02503	53	69.69934	0.52516
4	5.19848	0.03500	54	72.18086	0.53517
5	6.10614	0.04504	55	74.75074	0.54519
6	6.98129	0.05507	56	77.41211	0.55519
7	7.83171	0.06502	57	80.16824	0.56517
8	8.68098	0.07506	58	83.02249	0.57512
9	9.52665	0.08509	59	85.97837	0.58503
10	10.37142	0.09509	60	89.12852	0.59517
11	11.22360	0.10513	61	92.39410	0.60524
12	12.07317	0.11505	62	95.77932	0.61525
13	12.93522	0.12502	63	99.28857	0.62517
14	13.81734	0.13509	64	102.92640	0.63501
15	14.70071	0.14503	65	106.80422	0.64503
16	15.60933	0.15510	66	110.93897	0.65521
17	16.52448	0.16508	67	115.11866	0.66500
18	17.45835	0.17508	68	119.69487	0.67520
19	18.40816	0.18507	69	124.32866	0.68501
20	19.37088	0.19501	70	129.40027	0.69518
21	20.36359	0.20506	71	134.67875	0.70520
22	21.38578	0.21520	72	140.17255	0.71506
23	22.41443	0.22520	73	146.18240	0.72523
24	23.44564	0.23501	74	152.44992	0.73521
25	24.52429	0.24506	75	159.14515	0.74523
26	25.62694	0.25511	76	166.13441	0.75504
27	26.75242	0.26514	77	173.77768	0.76509
28	27.89942	0.27512	78	181.95437	0.77512
29	29.06653	0.28506	79	190.70632	0.78510
30	30.28246	0.29517	80	200.07913	0.79503
31	31.51774	0.30519	81	210.33264	0.80508
32	32.77063	0.31511	82	221.33274	0.81502
33	34.07334	0.32518	83	233.37420	0.82500
34	35.39243	0.33512	84	246.56318	0.83501
35	36.76259	0.34518	85	261.27983	0.84515
36	38.14764	0.35510	86	277.15177	0.85505
37	39.58488	0.36511	87	295.16565	0.86514
38	41.07626	0.37523	88	314.97941	0.87505
39	42.58126	0.38516	89	337.46980	0.88501
40	44.14139	0.39517	90	363.37760	0.89506
41	45.75868	0.40525	91	393.23473	0.90509
42	47.38784	0.41510	92	428.10488	0.91508
43	49.07500	0.42501	93	469.80893	0.92509
44	50.87306	0.43525	94	520.23461	0.93502
45	52.68431	0.44523	95	584.19062	0.94505
46	54.56004	0.45523	96	667.91882	0.95506
47	56.50256	0.46525	97	783.75319	0.96502
48	58.51424	0.47526	98	961.98735	0.97503
49	60.59754	0.48526	99	1289.31787	0.98502
50	62.75501	0.49524	100	2306.77318	0.99500

Appendix B: NEWTRANS.OUT

The NEWTRANS.OUT file is the puff information that is used in HPAC by the transport and diffusion code SCIPUFF. HPAC uses NewFall, or the selectable DELFIC cloud rise option to build the initial stabilized radiation cloud. NewFall is basically an empirical fit to data generated by DELFIC. Thus, it is a disk-tosser code like DELFIC is. However, SCIPUFF is a puff model and the data from NewFall, or DELFIC, must be translated into a form that SCIPUFF can understand. The result is the NEWTRANS.OUT file.

For HPAC Version 3.2.1, this file is sent to the C:\HPAC\DATA\TEMP\NWPNTEMP\ directory. NEWTRANS.OUT is most easily opened with WordPad because of its size and column format. WordPad preserves the original format and is easily read. The first page of the file is basic descriptive information about the contents of NEWTRANS.OUT. The rest of the file consists of the puff data that SCIPUFF uses. Included at the end of this Appendix is the NEWTRANS.OUT file created using HPAC Ultimate with a 1-megaton burst at 0.0 m HOB with 4 m/s fixed winds. The font and font size were changed in order to preserve the original column format.

The fourth line of the file gives the stabilization time of the cloud. Next gives the number of altitude layers along with the height of each layer in meters. The total number of puffs, also the total number of puff records in the file, that are needed is given next followed by the number of data fields in each puff record. Then the field names, for the data in the puff records, are listed along the units of each field. The next line gives the number of material types, which gives the number of materials used to comprise the puff

data, and for NWPN only 1 material is ever used; either U238TN, U238TNF, U238TNB, or U238TNBF depending on which scenario is used. The number of subgroups per material, which is the number of particle distribution groups, is given along with the material name and density. After this, the particle distribution is listed and includes the same number of groups that was given in the number of subgroups line plus an extra one. There is an extra one because these subgroup classes actually comprise the boundaries of the subgroups. Lastly, the puff data is given. This data includes puff number, material ID, subgroup ID, and field data.

In the file, there are as many puff records as given in the number of puffs line. The material ID is always the same throughout the file. The subgroup ID gives the particle distribution group number (with boundaries listed above) that that particular puff is comprised of.

The first field in the puff data is the concentration of the puff given in units of $\frac{rem \cdot m^2}{hour}$. Again from talking with Jim Furlong of SAIC, to get dose rate units of $\frac{rem}{hour}$, the concentration of the puff has to be divided by the individual puff volume (m^3), which gives $\frac{rem}{hour \cdot m}$, then vertically integrated (multiplied) with respect to the Z direction to get the desired $\frac{rem}{hour}$.

The X and the Y fields are always zero but the value of the Z component of the puff is listed. When examining the puff data, there will only be as many Z values as listed in the number of layers line in the file. Also, the height of each layer is congruent with the DZ listed. For this particular file, there are 15 layers with a DZ of 1071.2 m.

This value can be checked by subtracting subsequent layers (different Z values) from each other.

The MXX and MYY fields are always equal to each other (symmetric) and are the $\sigma 2$ of the puffs. The radius of a particular disk can be found by using the equation $\sqrt{2}\sqrt{MYY(\text{or MXX})}$ [Lamarche: 69]. In this particular file, the first layer is at a Z of 535.5945 m with an MXX and MYY of 1806832.1 m^2. The radius of this disk is then $\sqrt{2}\sqrt{1806832.1}$ or 1901 m (rounded). While scrolling down the file (up the cloud) the MYY and MXX values grow which shows an increasing radius of the cloud. Also, the number of particle groups per layer grows.

The MZZ field is equal to $\left(\frac{DZ}{2}\right)^2$. The top of each layer is found by adding $\sqrt{MZZ}$ to the Z value for the layer. This makes sense because $MZZ = \left(\frac{DZ}{2}\right)^2$ and $\sqrt{MZZ} = \frac{DZ}{2}$ which is half the layer height. Z is the center altitude of the layer so adding or subtracting half the layer height will give either the top or bottom altitude of the layer. Lastly, there is a SLH and an SL2 field. This number is found to be simply $\sqrt{MYY(\text{or MXX})}$ or σ.

Sample NEWTRANS.OUT File

```
No. Header Records      :     5
Input Format Type       :  NEWTRANS
Input File Name         :  C:\HPAC\DATA\TEMP\Nwpntemp\NEWTRANS.OUT
Time (s)                :   608.94820
No. Z Levels, DZ        :    15  1071.2
No. Puffs               :   222
No. Data Fields/Puff    :    13
Field Names             :  <C>        X          Y          Z
                           MXX        MXY        MXZ        MYY
                           MYZ        MZZ        <C2>       SLH
                           SL2
Field Units             :  remm2/hr   m          m          m
                           m2         m2         m2         m2
                           m2         m2         kg2/m3     m
                           m
No. Material Types      :     1
No. SubGroups/Material:      50
Material Names          :  U238TN
Mat. Density (kg/m3)    :   2600.0000
SubGroup Classes (m)    : Material No.  1 ( U238TN     ) :
  3.53596300E-06  4.08421400E-06  4.71745530E-06  5.44887820E-06  6.29370600E-06
  7.26952000E-06  8.39663100E-06  9.69849500E-06  1.12022100E-05  1.29390700E-05
  1.49452200E-05  1.72624200E-05  1.99388900E-05  2.30303330E-05  2.66011000E-05
  3.07254920E-05  3.54893600E-05  4.09918500E-05  4.73474710E-05  5.46885100E-05
  6.31677530E-05  7.29616600E-05  8.42740840E-05  9.73404530E-05  1.12432710E-04
  1.29865000E-04  1.50000020E-04  1.73256920E-04  2.00119720E-04  2.31147520E-04
  2.66986020E-04  3.08381200E-04  3.56194440E-04  4.11421030E-04  4.75210220E-04
  5.48889700E-04  6.33992900E-04  7.32291100E-04  8.45829900E-04  9.76972510E-04
  1.12844840E-03  1.30341000E-03  1.50549840E-03  1.73892000E-03  2.00853300E-03
  2.31994800E-03  2.67964700E-03  3.09511600E-03  3.57500100E-03  4.12929100E-03
  4.76952120E-03
Puff Data : Puff No., Material ID, SubGroup ID, Fields :
   1    1   44      9.89589900E+08    .00000000        .00000000        535.59450
                     1806832.1        .00000000        .00000000        1806832.1
                     .00000000        286861.43        .00000000        1344.1850
                     1344.1850
   2    1   48      1.26337000E+10    .00000000        .00000000        535.59450
                     4628698.0        .00000000        .00000000        4628698.0
                     .00000000        286861.43        .00000000        2151.4410
                     2151.4410
   3    1   41      8.84682000E+08    .00000000        .00000000        1606.7834
                     2374779.2        .00000000        .00000000        2374779.2
                     .00000000        286861.43        .00000000        1541.0320
                     1541.0320
   4    1   44      4.64856930E+09    .00000000        .00000000        1606.7834
                     5590633.0        .00000000        .00000000        5590633.0
                     .00000000        286861.43        .00000000        2364.4520
                     2364.4520
   5    1   48      2.28353020E+10    .00000000        .00000000        1606.7834
                     11415570.        .00000000        .00000000        11415570.
                     .00000000        286861.43        .00000000        3378.6940
                     3378.6940
   6    1   38      2.79417900E+08    .00000000        .00000000        2677.9724
                     2025917.0        .00000000        .00000000        2025917.0
                     .00000000        286861.43        .00000000        1423.3470
                     1423.3470
   7    1   40      8.31613310E+08    .00000000        .00000000        2677.9724
                     2940342.0        .00000000        .00000000        2940342.0
                     .00000000        286861.43        .00000000        1714.7430
                     1714.7430
   8    1   41      4.48998140E+09    .00000000        .00000000        2677.9724
                     7874625.0        .00000000        .00000000        7874625.0
                     .00000000        286861.43        .00000000        2806.1760
                     2806.1760
   9    1   44      6.28591820E+09    .00000000        .00000000        2677.9724
                     10672350.        .00000000        .00000000        10672350.
                     .00000000        286861.43        .00000000        3266.8562
                     3266.8562
```

10	1	37	8.62946430E+08	.00000000	.00000000	3749.1613
			4041960.0	.00000000	.00000000	4041960.0
			.00000000	286861.43	.00000000	2010.4630
			2010.4630			
11	1	38	1.59009420E+09	.00000000	.00000000	3749.1613
			6163792.0	.00000000	.00000000	6163792.0
			.00000000	286861.43	.00000000	2482.6984
			2482.6984			
12	1	40	4.40681210E+09	.00000000	.00000000	3749.1613
			10127001.	.00000000	.00000000	10127001.
			.00000000	286861.43	.00000000	3182.2951
			3182.2951			
13	1	41	6.24832400E+09	.00000000	.00000000	3749.1613
			15375031.	.00000000	.00000000	15375031.
			.00000000	286861.43	.00000000	3921.1010
			3921.1010			
14	1	44	1.60561810E+10	.00000000	.00000000	3749.1613
			18321490.	.00000000	.00000000	18321490.
			.00000000	286861.43	.00000000	4280.3610
			4280.3610			
15	1	35	1.11909810E+09	.00000000	.00000000	4820.3510
			4163996.4	.00000000	.00000000	4163996.4
			.00000000	286861.43	.00000000	2040.5872
			2040.5872			
16	1	36	8.85665530E+08	.00000000	.00000000	4820.3510
			4292027.0	.00000000	.00000000	4292027.0
			.00000000	286861.43	.00000000	2071.7210
			2071.7210			
17	1	37	2.53662230E+09	.00000000	.00000000	4820.3510
			11014930.	.00000000	.00000000	11014930.
			.00000000	286861.43	.00000000	3318.8750
			3318.8750			
18	1	38	3.71259410E+09	.00000000	.00000000	4820.3510
			13862472.	.00000000	.00000000	13862472.
			.00000000	286861.43	.00000000	3723.2341
			3723.2341			
19	1	40	6.22767200E+09	.00000000	.00000000	4820.3510
			20009940.	.00000000	.00000000	20009940.
			.00000000	286861.43	.00000000	4473.2470
			4473.2470			
20	1	41	9.76941800E+09	.00000000	.00000000	4820.3510
			23905980.	.00000000	.00000000	23905980.
			.00000000	286861.43	.00000000	4889.3740
			4889.3740			
21	1	44	7.48874230E+09	.00000000	.00000000	4820.3510
			25062202.	.00000000	.00000000	25062202.
			.00000000	286861.43	.00000000	5006.2163
			5006.2163			
22	1	33	6.44733100E+08	.00000000	.00000000	5891.5390
			3948562.2	.00000000	.00000000	3948562.2
			.00000000	286861.43	.00000000	1987.0990
			1987.0990			
23	1	34	8.54012410E+08	.00000000	.00000000	5891.5390
			5222042.0	.00000000	.00000000	5222042.0
			.00000000	286861.43	.00000000	2285.1790
			2285.1790			
24	1	35	2.39666200E+09	.00000000	.00000000	5891.5390
			8440348.0	.00000000	.00000000	8440348.0
			.00000000	286861.43	.00000000	2905.2280
			2905.2280			
25	1	36	2.51066500E+09	.00000000	.00000000	5891.5390
			11360874.	.00000000	.00000000	11360874.
			.00000000	286861.43	.00000000	3370.5900
			3370.5900			
26	1	37	5.10843230E+09	.00000000	.00000000	5891.5390
			21716960.	.00000000	.00000000	21716960.
			.00000000	286861.43	.00000000	4660.1460
			4660.1460			
27	1	38	6.73208110E+09	.00000000	.00000000	5891.5390
			24810221.	.00000000	.00000000	24810221.
			.00000000	286861.43	.00000000	4980.9863

			4980.9863			
28	1	40	9.80633600E+09	.00000000	.00000000	5891.5390
			31325341.	.00000000	.00000000	31325341.
			.00000000	286861.43	.00000000	5596.9050
			5596.9050			
29	1	41	1.40765920E+10	.00000000	.00000000	5891.5390
			34341220.	.00000000	.00000000	34341220.
			.00000000	286861.43	.00000000	5860.1380
			5860.1380			
30	1	30	4.12964900E+08	.00000000	.00000000	6962.7290
			6571978.0	.00000000	.00000000	6571978.0
			.00000000	286861.43	.00000000	2563.5870
			2563.5870			
31	1	31	1.34255340E+09	.00000000	.00000000	6962.7290
			6726902.0	.00000000	.00000000	6726902.0
			.00000000	286861.43	.00000000	2593.6271
			2593.6271			
32	1	32	9.51857300E+08	.00000000	.00000000	6962.7290
			6552366.4	.00000000	.00000000	6552366.4
			.00000000	286861.43	.00000000	2559.7590
			2559.7590			
33	1	33	2.87009810E+09	.00000000	.00000000	6962.7290
			9176360.0	.00000000	.00000000	9176360.0
			.00000000	286861.43	.00000000	3029.2510
			3029.2510			
34	1	34	2.16350000E+09	.00000000	.00000000	6962.7290
			12595532.	.00000000	.00000000	12595532.
			.00000000	286861.43	.00000000	3549.0190
			3549.0190			
35	1	35	6.47915000E+09	.00000000	.00000000	6962.7290
			16876792.	.00000000	.00000000	16876792.
			.00000000	286861.43	.00000000	4108.1372
			4108.1372			
36	1	36	4.97852410E+09	.00000000	.00000000	6962.7290
			22085211.	.00000000	.00000000	22085211.
			.00000000	286861.43	.00000000	4699.4910
			4699.4910			
37	1	37	8.57837510E+09	.00000000	.00000000	6962.7290
			36153900.	.00000000	.00000000	36153900.
			.00000000	286861.43	.00000000	6012.8120
			6012.8120			
38	1	38	1.06485520E+10	.00000000	.00000000	6962.7290
			39009020.	.00000000	.00000000	39009020.
			.00000000	286861.43	.00000000	6245.7202
			6245.7202			
39	1	40	1.41965700E+10	.00000000	.00000000	6962.7290
			45206520.	.00000000	.00000000	45206520.
			.00000000	286861.43	.00000000	6723.5791
			6723.5791			
40	1	27	1.99140120E+09	.00000000	.00000000	8033.9170
			16135180.	.00000000	.00000000	16135180.
			.00000000	286861.43	.00000000	4016.8620
			4016.8620			
41	1	28	1.46571430E+09	.00000000	.00000000	8033.9170
			12150950.	.00000000	.00000000	12150950.
			.00000000	286861.43	.00000000	3485.8210
			3485.8210			
42	1	29	1.96806020E+09	.00000000	.00000000	8033.9170
			10338320.	.00000000	.00000000	10338320.
			.00000000	286861.43	.00000000	3215.3254
			3215.3254			
43	1	30	1.77310800E+09	.00000000	.00000000	8033.9170
			9651972.0	.00000000	.00000000	9651972.0
			.00000000	286861.43	.00000000	3106.7622
			3106.7622			
44	1	31	2.38136000E+09	.00000000	.00000000	8033.9170
			11693801.	.00000000	.00000000	11693801.
			.00000000	286861.43	.00000000	3419.6201
			3419.6201			
45	1	32	2.13958910E+09	.00000000	.00000000	8033.9170
			14254601.	.00000000	.00000000	14254601.

			.00000000	286861.43	.00000000	3775.5270
			3775.5270			
46	1	33	4.24702230E+09	.00000000	.00000000	8033.9170
			17345490.	.00000000	.00000000	17345490.
			.00000000	286861.43	.00000000	4164.7920
			4164.7920			
47	1	34	4.07933000E+09	.00000000	.00000000	8033.9170
			23376603.	.00000000	.00000000	23376603.
			.00000000	286861.43	.00000000	4834.9360
			4834.9360			
48	1	35	8.20266130E+09	.00000000	.00000000	8033.9170
			28094040.	.00000000	.00000000	28094040.
			.00000000	286861.43	.00000000	5300.3813
			5300.3813			
49	1	36	8.28924100E+09	.00000000	.00000000	8033.9170
			36470052.	.00000000	.00000000	36470052.
			.00000000	286861.43	.00000000	6039.0440
			6039.0440			
50	1	37	1.29464520E+10	.00000000	.00000000	8033.9170
			54326800.	.00000000	.00000000	54326800.
			.00000000	286861.43	.00000000	7370.6720
			7370.6720			
51	1	38	1.54620110E+10	.00000000	.00000000	8033.9170
			56459320.	.00000000	.00000000	56459320.
			.00000000	286861.43	.00000000	7513.9420
			7513.9420			
52	1	3	2.14963700E+10	.00000000	.00000000	9105.1064
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
53	1	7	1.39726400E+10	.00000000	.00000000	9105.1064
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
54	1	10	1.10168900E+10	.00000000	.00000000	9105.1064
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
55	1	11	9.67336440E+09	.00000000	.00000000	9105.1064
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
56	1	13	8.59854640E+09	.00000000	.00000000	9105.1064
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
57	1	14	7.79243310E+09	.00000000	.00000000	9105.1064
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
58	1	15	7.25502410E+09	.00000000	.00000000	9105.1064
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
59	1	16	1.37039330E+10	.00000000	.00000000	9105.1064
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
60	1	17	6.18020500E+09	.00000000	.00000000	9105.1064
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
61	1	18	1.20917100E+10	.00000000	.00000000	9105.1064
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
62	1	19	5.64279600E+09	.00000000	.00000000	9105.1064
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
63	1	20	1.07481820E+10	.00000000	.00000000	9105.1064

			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
64	1	21	1.02107740E+10	.00000000	.00000000	9105.1064
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
65	1	22	9.67336440E+09	.00000000	.00000000	9105.1064
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
66	1	23	9.40466000E+09	.00000000	.00000000	9105.1064
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
67	1	24	1.23782100E+10	.00000000	.00000000	9105.1064
			67837940.	.00000000	.00000000	67837940.
			.00000000	286861.43	.00000000	8236.3790
			8236.3790			
68	1	25	1.49459900E+10	.00000000	.00000000	9105.1064
			66098560.	.00000000	.00000000	66098560.
			.00000000	286861.43	.00000000	8130.1020
			8130.1020			
69	1	26	1.41502200E+10	.00000000	.00000000	9105.1064
			64062032.	.00000000	.00000000	64062032.
			.00000000	286861.43	.00000000	8003.8760
			8003.8760			
70	1	27	5.18146810E+09	.00000000	.00000000	9105.1064
			41791100.	.00000000	.00000000	41791100.
			.00000000	286861.43	.00000000	6464.6030
			6464.6030			
71	1	28	1.38462820E+10	.00000000	.00000000	9105.1064
			63136532.	.00000000	.00000000	63136532.
			.00000000	286861.43	.00000000	7945.8500
			7945.8500			
72	1	29	1.44704800E+10	.00000000	.00000000	9105.1064
			63037360.	.00000000	.00000000	63037360.
			.00000000	286861.43	.00000000	7939.6070
			7939.6070			
73	1	30	1.41625100E+10	.00000000	.00000000	9105.1064
			62987290.	.00000000	.00000000	62987290.
			.00000000	286861.43	.00000000	7936.4531
			7936.4531			
74	1	31	1.59819700E+10	.00000000	.00000000	9105.1064
			63238540.	.00000000	.00000000	63238540.
			.00000000	286861.43	.00000000	7952.2670
			7952.2670			
75	1	32	9.11086200E+09	.00000000	.00000000	9105.1064
			63720411.	.00000000	.00000000	63720411.
			.00000000	286861.43	.00000000	7982.5063
			7982.5063			
76	1	33	1.95858320E+10	.00000000	.00000000	9105.1064
			64037072.	.00000000	.00000000	64037072.
			.00000000	286861.43	.00000000	8002.3164
			8002.3164			
77	1	34	1.11590130E+10	.00000000	.00000000	9105.1064
			65422620.	.00000000	.00000000	65422620.
			.00000000	286861.43	.00000000	8088.4252
			8088.4252			
78	1	35	2.13979600E+10	.00000000	.00000000	9105.1064
			58517440.	.00000000	.00000000	58517440.
			.00000000	286861.43	.00000000	7649.6694
			7649.6694			
79	1	36	1.30542010E+10	.00000000	.00000000	9105.1064
			57741060.	.00000000	.00000000	57741060.
			.00000000	286861.43	.00000000	7598.7534
			7598.7534			
80	1	37	8.39192200E+09	.00000000	.00000000	9105.1064
			69825330.	.00000000	.00000000	69825330.
			.00000000	286861.43	.00000000	8356.1552
			8356.1552			

81	1	3	4.29927400E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
82	1	7	2.79452800E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
83	1	10	2.20337800E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
84	1	11	1.93467300E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
85	1	13	1.71970920E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
86	1	14	1.55848700E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
87	1	15	1.45100500E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
88	1	16	2.74078700E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
89	1	17	1.23604100E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
90	1	18	2.41834120E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
91	1	19	1.12855920E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
92	1	20	2.14963700E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
93	1	21	2.04215500E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
94	1	22	1.93467300E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
95	1	23	1.88093200E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
96	1	24	1.38981800E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
97	1	25	8.84866900E+09	.00000000	.00000000	10176.294
			75652850.	.00000000	.00000000	75652850.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
98	1	26	1.78741800E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642

			8697.8642			
99	1	27	1.87678630E+10	.00000000	.00000000	10176.294
			75652850.	.00000000	.00000000	75652850.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
100	1	28	1.37648800E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
101	1	29	1.42727500E+10	.00000000	.00000000	10176.294
			75652850.	.00000000	.00000000	75652850.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
102	1	30	1.89749800E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
103	1	31	1.57761400E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
104	1	32	5.83563920E+09	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
105	1	33	2.47735020E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
106	1	34	6.72296600E+09	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
107	1	35	2.98261500E+10	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
108	1	36	8.70645700E+09	.00000000	.00000000	10176.294
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
109	1	3	2.14963700E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
110	1	7	1.39726400E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
111	1	10	1.10168900E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
112	1	11	9.67336440E+09	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
113	1	13	8.59854640E+09	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
114	1	14	7.79243310E+09	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
115	1	15	7.25502410E+09	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
116	1	16	1.37039330E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.

			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
117	1	17	6.18020500E+09	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
118	1	18	1.20917100E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
119	1	19	1.12855920E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
120	1	20	2.14963700E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
121	1	21	2.04215500E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
122	1	22	1.93467300E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
123	1	23	1.88093200E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
124	1	24	1.85547900E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
125	1	25	1.76973400E+10	.00000000	.00000000	11247.484
			75652850.	.00000000	.00000000	75652850.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
126	1	26	1.34148700E+10	.00000000	.00000000	11247.484
			75652850.	.00000000	.00000000	75652850.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
127	1	27	1.87678630E+10	.00000000	.00000000	11247.484
			75652850.	.00000000	.00000000	75652850.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
128	1	28	1.37453100E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
129	1	29	1.93204030E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
130	1	30	1.42413040E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
131	1	31	2.10183740E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
132	1	32	1.16712800E+10	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
133	1	33	1.82530600E+10	.00000000	.00000000	11247.484
			75652850.	.00000000	.00000000	75652850.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
134	1	34	1.34459310E+10	.00000000	.00000000	11247.484

			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
135	1	35	7.42782200E+09	.00000000	.00000000	11247.484
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
136	1	3	4.29927400E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
137	1	7	2.79452800E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
138	1	10	2.20337800E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
139	1	11	1.93467300E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
140	1	13	1.71970920E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
141	1	14	1.55848700E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
142	1	15	1.45100500E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
143	1	16	2.74078700E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
144	1	17	1.23604100E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
145	1	18	2.41834120E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
146	1	19	5.64279600E+09	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
147	1	20	1.07481820E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
148	1	21	1.02107740E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
149	1	22	9.67336440E+09	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
150	1	23	9.40466000E+09	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
151	1	24	1.85547900E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			

152	1	25	1.76973400E+10	.00000000	.00000000	12318.672
			75652850.	.00000000	.00000000	75652850.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
153	1	26	1.33964000E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
154	1	27	1.39373200E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
155	1	28	1.83401300E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
156	1	29	1.47078600E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
157	1	30	1.42211630E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
158	1	31	1.57514220E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
159	1	32	1.16712800E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
160	1	33	1.23867510E+10	.00000000	.00000000	12318.672
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
161	1	3	4.29927400E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
162	1	7	2.79452800E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
163	1	10	2.20337800E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
164	1	11	1.93467300E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
165	1	13	1.71970920E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
166	1	14	1.55848700E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
167	1	15	1.45100500E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
168	1	16	2.74078700E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
169	1	17	1.23604100E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642

			8697.8642			
170	1	18	2.41834120E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
171	1	19	1.12855920E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
172	1	20	2.14963700E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
173	1	21	2.04215500E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
174	1	22	1.93467300E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
175	1	23	1.88093200E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
176	1	24	9.27739300E+09	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
177	1	25	1.76973400E+10	.00000000	.00000000	13389.862
			75652850.	.00000000	.00000000	75652850.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
178	1	26	1.78741800E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
179	1	27	1.42144800E+10	.00000000	.00000000	13389.862
			75652850.	.00000000	.00000000	75652850.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
180	1	28	1.83401300E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
181	1	29	1.42727500E+10	.00000000	.00000000	13389.862
			75652850.	.00000000	.00000000	75652850.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
182	1	30	1.89749800E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
183	1	31	1.05091900E+10	.00000000	.00000000	13389.862
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
184	1	3	2.14963700E+10	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
185	1	7	1.39726400E+10	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
186	1	10	1.10168900E+10	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
187	1	11	9.67336440E+09	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.

			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
188	1	13	8.59854640E+09	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
189	1	14	7.79243310E+09	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
190	1	15	7.25502410E+09	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
191	1	16	1.37039330E+10	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
192	1	17	6.18020500E+09	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
193	1	18	1.20917100E+10	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
194	1	19	1.12855920E+10	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
195	1	20	2.14963700E+10	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
196	1	21	2.04215500E+10	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
197	1	22	1.93467300E+10	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
198	1	23	1.88093200E+10	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
199	1	24	1.85547900E+10	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
200	1	25	8.84866900E+09	.00000000	.00000000	14461.050
			75652850.	.00000000	.00000000	75652850.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
201	1	26	1.34148700E+10	.00000000	.00000000	14461.050
			75652850.	.00000000	.00000000	75652850.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
202	1	27	1.87678630E+10	.00000000	.00000000	14461.050
			75652850.	.00000000	.00000000	75652850.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
203	1	28	9.17006330E+09	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
204	1	29	9.66020200E+09	.00000000	.00000000	14461.050
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
205	1	3	4.29927400E+10	.00000000	.00000000	15532.240

			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
206	1	7	2.79452800E+10	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
207	1	10	2.20337800E+10	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
208	1	11	1.93467300E+10	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
209	1	13	1.71970920E+10	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
210	1	14	1.55848700E+10	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
211	1	15	1.45100500E+10	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
212	1	16	2.74078700E+10	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
213	1	17	1.23604100E+10	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
214	1	18	2.41834120E+10	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
215	1	19	5.64279600E+09	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
216	1	20	1.07481820E+10	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
217	1	21	1.02107740E+10	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
218	1	22	9.67336440E+09	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
219	1	23	9.40466000E+09	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
220	1	24	9.27739300E+09	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
221	1	25	8.84866900E+09	.00000000	.00000000	15532.240
			75652850.	.00000000	.00000000	75652850.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			
222	1	26	4.45930800E+09	.00000000	.00000000	15532.240
			75652840.	.00000000	.00000000	75652840.
			.00000000	286861.43	.00000000	8697.8642
			8697.8642			

Appendix C: Sample HPAC Output Data

Note: This appendix includes only the first page of data where the X (km) and Y (km) values are Cartesian coordinate system values centered on ground zero (GZ)

```
#Project :mytest#1
#Path    :C:\HPAC\RUNS\
#Created :Tue Nov 14 12:05:12 2000
#Version :T:0.24-S:1.34
#Title(s):Radiation Dose To Aircrew Flying Through a Nuclear Cloud
#        :Horizontal Slice at z = 1.00E+04m
#        :Total U238TN at 20-Oct-00 16:00Z (4.00 hrs)
#Units   :rem/hr@1hr/m3
#Entries :30000
#
#     X (km)          Y (km)            Data
#============= =============   =============
     -95.0000        0.000000    1.928259E-20
     -94.9937        0.000000    1.956892E-20
     -94.9873        0.000000    1.985950E-20
     -94.9810        0.000000    2.015440E-20
     -94.9747        0.000000    2.045368E-20
     -94.9683        0.000000    2.076294E-20
     -94.9620        0.000000    2.107125E-20
     -94.9557        0.000000    2.138414E-20
     -94.9493        0.000000    2.170751E-20
     -94.9430        0.000000    2.202985E-20
     -94.9367        0.000000    2.235693E-20
     -94.9303        0.000000    2.269502E-20
     -94.9240        0.000000    2.303202E-20
     -94.9177        0.000000    2.337403E-20
     -94.9113        0.000000    2.372745E-20
     -94.9050        0.000000    2.407978E-20
     -94.8987        0.000000    2.443735E-20
     -94.8923        0.000000    2.480022E-20
     -94.8860        0.000000    2.516848E-20
     -94.8797        0.000000    2.554221E-20
     -94.8733        0.000000    2.592846E-20
     -94.8670        0.000000    2.631348E-20
     -94.8607        0.000000    2.670416E-20
     -94.8543        0.000000    2.710798E-20
     -94.8480        0.000000    2.751051E-20
     -94.8417        0.000000    2.791902E-20
     -94.8353        0.000000    2.834116E-20
     -94.8290        0.000000    2.876201E-20
     -94.8227        0.000000    2.918910E-20
     -94.8163        0.000000    2.963050E-20
     -94.8100        0.000000    3.007049E-20
     -94.8037        0.000000    3.051701E-20
     -94.7973        0.000000    3.097843E-20
     -94.7910        0.000000    3.143844E-20
     -94.7847        0.000000    3.190527E-20
     -94.7783        0.000000    3.237904E-20
```

Appendix D: Single Route Dose Calculation Program (FORTRAN)

Note: This program is simply a modified version of the program in Appendix D that handles only a single aircraft route.

```
Program DoseRateCalculation

Use Subroutines1
Use Subroutines2
Use Subroutines3
Use Subroutines4
Use Subroutines5
Use Subroutines7
Use Subroutines9
Use Subroutines10

Implicit None

!   11/29/00    (fegii)

Integer :: i
Integer :: nofdpoints, nofpgroups

!Below dimensions the input data for 2, 4, 6, 8, 10, and 12
!THOUSAND METER heights above ground inside a nuclear cloud;
!These arrays contain the actual table data from NWPN

Real(8), Allocatable :: AircraftNonPart(:,:), AircraftPartGrps(:,:)
Real(8), Dimension(1,6) :: AircraftDose
Real(8) :: Altitude
Real(8) :: TAB  !Time after burst that data files are from
Real(8) :: MD   !Mission duration in hours
Character(Len=15) :: dosefilename   !name of file specified by user
                                    !for dose informatin to be
                                    !written to
Character(Len=15) :: dosefile   !name that this program uses to write
                                !data too:  is the same data as
                                !"dosefilename"
AircraftDose=0

!Output filename needs to be specified
!Print*
Print*,"Please enter a file name to store output dose &
        &data to (15 character max):"
Print*
Print*,"Note: This file will become an ASCII text file..."
Read*, dosefilename

dosefile=Trim(ADJUSTL(ADJUSTR(dosefilename)//'.txt'))

Print *
Print *, "How many data points are in the data files? (Integer Value)"
Read *, nofdpoints
!Print *
Print *, "How many particle groups will be used for filter information?"
Read *, nofpgroups
!Print*
Print *, "What is the time after burst? (hours)"
Read *, TAB
Print *, "What is the mission duration from time of cloud entry? (hours)"
Read *, MD
Print *

Allocate(AircraftNonPart(nofdpoints+1,2))
Allocate(AircraftPartGrps(nofdpoints+1,nofpgroups*2))
```

```
Call OpenFilesNonFiltered(nofdpoints, AircraftNonPart, Altitude)

Call OpenFilesFiltered(nofdpoints, nofpgroups, AircraftPartGrps, Altitude)

Call SkyShine(TAB, nofdpoints, AircraftNonPart, AircraftDose)

Call CabinIngestion(TAB, MD, nofdpoints, AircraftNonPart, AircraftDose)

Call FiltCabinIngestion(TAB, MD, nofdpoints, AircraftPartGrps, AircraftDose)

Call AddingDose(AircraftDose)

Call FinalPrint(AircraftDose, dosefile, TAB)

EndProgram DoseRateCalculation
```

```
Module Subroutines1

Implicit None

Contains

!--------------------------------------------------------------------------------
!------------------------Subroutine OpenFileNonFiltered----------------------
!--------------------------------------------------------------------------------
!  This subroutine processes the files that will be used for the non-
!  filtered dose calculations.  These files are different because they
!  contain all particle size groups (20 from U238TN.mtl).

Subroutine OpenFilesNonFiltered(nofdpoints, AircraftNonPart, Altitude)

Integer :: i, j !  Counters for Do Loops
Integer, Intent(IN) :: nofdpoints  ! Number of Data Points used
Character(Len=100), Dimension(12,1) :: Header  ! Reads Header Information
Character(Len=50) :: fname  !  Used to read in file name

!  Below are the array names that will be used by this program.
!  These arrays hold the dose rate density and X position values
!  that HPAC outputs.

Real(8), Dimension(nofdpoints+1,2), Intent(OUT) :: AircraftNonPart
Real(8), Intent(OUT) :: Altitude
Real(8) :: PlaceHolder  ! Reads the Y-Value which is always zero

Print *, "What is the name of data file?"
Read (*,'(A50)') fname
fname=Trim(fname)
Print *
Print *, "What altitude is this data file at? (m)"
Read *, Altitude
Print *

        Open (Unit=10, Status="unknown", File=fname)

        Do i=1,12,1 !This Do Loop reads in the header information that each
                    !data file contains.  This information can be discarded,
                    !but needs to be read so that the data will be read to the
                    !correct array value.
            Read(10,101) Header(i,1)

        End Do

        AircraftNonPart(1,1)=Altitude

        Do j=1,nofdpoints,1 !This Do Loop reads in the necessary data from
                            !the data files.  The If Statments are needed to
                            !distinguish between the files.
                Read(10,*) AircraftNonPart(j+1,1), PlaceHolder, AircraftNonPart(j+1,2)
```

```
        End Do

101 Format(A70)

End Subroutine OpenFilesNonFiltered


!----------------------------------------------------------------------------------
!-----------------------Subroutine OpenFileFiltered--------------------------------
!----------------------------------------------------------------------------------
!  This subroutine processes the files that will be used for the filtered
!  dose calculations.  These files include only 5 particle groups from the
!  U238TN.mtl material file. There are more files here because for each altitude
!  and each time, there are 5 more files (the individual particle group files).

Subroutine OpenFilesFiltered(nofdpoints, nofpgroups, AircraftPartGrps, Altitude)

Integer :: i, j, k, l, m  !Counters for Do Loops
Integer, Intent(IN) :: nofdpoints, nofpgroups   !Number of Data Points and groups used

!  Below are the array names that will be used by this program.
!  These arrays hold the X position and dose rate density values
!  that HPAC outputs.
Real(8), Intent(IN) :: Altitude
Real(8), Dimension(nofdpoints+1,nofpgroups*2), Intent(OUT) :: AircraftPartGrps

Real(8) :: PlaceHolder  !Reads the Y-Value which is always zero


Character(Len=100), Dimension(12,1) :: Header  !Reads Header Information
Character(Len=50) :: fname  !Used to read in file name

        i=1 !Sets the counter as the first group
        AircraftPartGrps(1,1)=Altitude  !Sets the first data location as the altitude

        Do While (i<=nofpgroups)    !This Do Loop correctly identifies which particle
group
                                !is being read.  The name then gets modified to include
                                !particle group information.

            Print *, "What is the name of the particle group data file?"
            Read (*,'(A50)') fname
            fname=Trim(fname)
            Print *

            Open (Unit=10, Status="unknown", File=fname)

            Do k=1,12,1 !This Do Loop reads in the header information that each
                        !data file contains.  This information can be discarded,
                        !but needs to be read so that the data will be read to the
                        !correct array value.

                Read(10,101) Header(k,1)
            End Do

            Do l=1,nofdpoints,1 !Do Loop to read in the data

                Read(10,*) AircraftPartGrps(l+1,i), PlaceHolder, &
                           & AircraftPartGrps(l+1,i+nofpgroups)
            End Do

            i=i+1

        End Do

101 Format(A70)


End Subroutine OpenFilesFiltered

!----------------------------------------------------------------------------------
```

```
End Module Subroutines1

------------------------------------------------------------------------------------------

Module Subroutines2

Implicit None

Contains


!---------------------------------------------------------------------
!------------------------Subroutine Atmosphere-----------------------
!-------------------[US Standard Atmosphere, 1976]-------------------

Subroutine Atmosphere(Z, Density)

    Real(8), Intent(IN) :: Z  ! Meters
    Real(8) :: MeanFreePath ! m
    Real(8), Intent(OUT) :: Density !kg/m^3
    Real(8) :: MACASL   !Mass Attenuation Coefficient for Air @ 0.0 m
                        !m^2/kg
    Real(8) :: Temp, Pressure  !K, Pa
    Real(8) :: SpeedSound  !  m/s
    Real(8) :: Lk, Tk, Pk, Zk

    MACASL=6.73015E-3

    If (Z>47000 .AND. Z <= 51000) Then
            Zk=47000
            Lk=0
            Tk=270.65
            Pk=115.8
        Else If (Z>32000 .AND. Z <= 47000) Then
            Zk=32000
            Lk=0.0028
            Tk=228.67
            Pk=888.8
        Else If (Z>20000 .AND. Z <= 32000) Then
            Zk=20000
            Lk=0.0010
            Tk=216.65
            Pk=5528
        Else If (Z>11000 .AND. Z <= 20000) Then
            Zk=11000
            Lk=0
            Tk=216.65
            Pk=22690
        Else !If (Z>0 .AND. Z <= 11000) Then
            Zk=0
            Lk=-0.006545
            Tk=288.15
            Pk=101300
    End If

    Temp=Tk+Lk*(Z-Zk)

    If (Lk==0) Then
            Pressure=Pk*(Exp((-0.034164*(Z-Zk))/Tk))
        Else
            Pressure=Pk*(Tk/Temp)**(0.034164/Lk)
    End If

    Density=0.003484*(Pressure/Temp)
    SpeedSound=SQRT(401.9*Temp)


    MeanFreePath=(MACASL*Density)**(-1.0)
```

```
End Subroutine Atmosphere

!-----------------------------------------------------------------

!-----------------------------------------------------------------

End Module Subroutines2

----------------------------------------------------------------------------------------

Module Subroutines3

Use Subroutines2
Use Subroutines11

Implicit None

Contains

!-------------------------------------------------------------
!------------------Aircraft Data-----------------------------
!------------------Same as B1B Data--------------------------

Subroutine Aircraft(Velocity, CabinRadius, PV, PSL, GammaTFactor, MassFlow)

Real(8), Intent(OUT) :: Velocity        !m/s
Real(8), Intent(OUT) :: CabinRadius     !m
Real(8), Intent(OUT) :: GammaTFactor    ! Unitless
Real(8), Intent(OUT) :: MassFlow    ! kg/min
Real(8), Intent(OUT) :: PV  ! m^3
Real(8), Intent(OUT) :: PSL !PseudoLength

Real(8) :: CabinMass     !kg
Real(8) :: CabinArea     !m^2
Real(8) :: MACAL         !m^2/kg, Mass attenuation coefficient for
                         !aluminum for 1MeV gamma rays
Real(8) :: ACMassIntegral   !kg/m^2,
                            !Shielding by aircraft skin and equipment

Velocity=279.2
CabinMass=11511
CabinArea=107.9
MACAL=6.01271E-3
CabinRadius=1.07
PV=28.3
PSL=PV/(3.14159265359*CabinRadius**2.0)
ACMassIntegral=CabinMass/CabinArea
GammaTFactor=Exp(-MACAL*ACMassIntegral)
MassFlow=17.0/60.0  ! Convert to kg/s

End Subroutine Aircraft

!-------------------------------------------------------------
!---------Subroutine CalculationsSS--------------------------
!-------------------------------------------------------------

Subroutine CalculationsSS(Altitude, Velocity, GammaTFactor, &
                & DeltaX, MFactor, Time)

Real(8), Intent(IN) :: Altitude, Velocity, GammaTFactor
Real(8), Intent(IN) :: DeltaX
Real(8), Intent(IN) :: Time !Time after burst
Real(8), Intent(OUT):: MFactor  ! Multiplication Factor that gets outputed.

Real(8) :: Density
Real(8) :: PseudoVolume
Real(8) :: tincell  !Time in each cell
Real(8) :: MAC

MAC=0.0063015 !m^2/kg for 1 MeV gamma rays [Conners: 104]
```

```
Call Atmosphere(Altitude, Density)
            PseudoVolume=1.0/(MAC*Density)
            tincell=DeltaX/Velocity/3600.0  !Converting to Hours
            MFactor=tincell*GammaTFactor*PseudoVolume*Time**-1.3

End Subroutine CalculationsSS


!--------------------------------------------------------------
!---------Subroutine CalculationsCI--------------------------
!--------------------------------------------------------------

Subroutine CalculationsCI(Altitude, Velocity, CabinRadius, PV, PSL, MassFlow, &
                    & DeltaX, MFactor, InitialTime, MissionDuration)

Real(8), Intent(IN) :: Altitude, Velocity, MassFlow, CabinRadius, PV, PSL
Real(8), Intent(IN) :: DeltaX
Real(8), Intent(IN) :: InitialTime, MissionDuration
Real(8), Intent(OUT) :: MFactor
Real(8) :: DecayIntegral    !Used for dose and decay
Real(8) :: IntegralMultiplier   !used for New Cabin Integral (Spherical Cabin)
Real(8) :: Density
Real(8) :: EffInletArea
Real(8) :: Altitude2
Real(8) :: MAC  !Mass Attenuation Coefficient (air)
Real(8) :: K    ! Cabin Geometry Factor (Result of Simpsons DI and complex cabin
                ! geometries)

MAC=0.0063015 !m^2/kg for 1 MeV gamma rays [Conners: 104]

    If (Altitude>=2438.4) Then  !8000 feet where the cabin is pressurized at
        Altitude2=2438.4
    Else
        Altitude2=Altitude
    End IF

Call Atmosphere(Altitude, Density)
EffInletArea=MassFlow/Velocity/Density

Call Atmosphere(Altitude2, Density)
!Call SimpsonsDI(CabinRadius, PSL, MAC, Density, K)
IntegralMultiplier=(1.0/(MAC*Density))*(1-Exp(-MAC*Density*CabinRadius))
DecayIntegral=((1.0/0.3)*((1/(InitialTime**0.3))-
(1/((InitialTime+MissionDuration)**0.3))))
MFactor=(1.0/PV)*EffInletArea*DeltaX*DecayIntegral*IntegralMultiplier   !*K

End Subroutine CalculationsCI

!--------------------------------------------------------------
!---------Subroutine CalculationsFCI--------------------------
!--------------------------------------------------------------

Subroutine CalculationsFCI(j, Altitude, Velocity, CabinRadius, PV, PSL, MassFlow, &
                    & DeltaX, MFactor, InitialTime, MissionDuration)

Integer, Intent(IN) :: j
Real(8), Intent(IN) :: Altitude, Velocity, MassFlow, CabinRadius, PV, PSL
Real(8), Intent(IN) :: DeltaX
Real(8), Intent(IN) :: InitialTime, MissionDuration
Real(8), Intent(OUT) :: MFactor
Real(8) :: DecayIntegral
Real(8) :: IntegralMultiplier   !used for New Cabin Integral (Spherical Cabin)
Real(8) :: Density
Real(8) :: Altitude2
Real(8) :: EffInletArea
Real(8) :: FilterFactor
Real(8) :: MAC  !Mass Attenuation Coefficient (air)
Real(8) :: K    ! Cabin Geometry Factor (Result of Simpsons DI and complex cabin
                ! geometries)
```

```
MAC=0.0082 !m^2/kg for 0.7 MeV gamma rays

If (Altitude>=2438.4) Then  !8000 feet where the cabin is pressurized at
    Altitude2=2438.4
Else
    Altitude2=Altitude
End IF

If (j==1 .OR. j==2 .OR. j==3) Then
    FilterFactor=1.0
Else
    FilterFactor=0.1
End IF

Call Atmosphere(Altitude, Density)
EffInletArea=MassFlow/Velocity/Density

Call Atmosphere(Altitude2, Density)
!Call SimpsonsDI(CabinRadius, PSL, MAC, Density, K)
IntegralMultiplier=(1.0/(MAC*Density))*(1-Exp(-MAC*Density*CabinRadius))
DecayIntegral=((1.0/0.3)*((1/(InitialTime**0.3))-
(1/((InitialTime+MissionDuration)**0.3))))
MFactor=(1.0/PV)*EffInletArea*DeltaX*DecayIntegral*FilterFactor*IntegralMultiplier  !*K

End Subroutine CalculationsFCI

!-------------------------------------------------------------
!---------Subroutine DeltaX-----------------------------------
!-------------------------------------------------------------

Subroutine DeltaXValue(k, CellBoundary1, CellBoundary2, CellBoundary3, &
                    &DeltaX, DeltaXF)

Integer :: k
Real(8), Intent(IN) :: CellBoundary1, CellBoundary2, CellBoundary3
Real(8), Intent(OUT) :: DeltaX, DeltaXF

If (k==2) Then
    DeltaX=(ABS(CellBoundary2-CellBoundary3)/2.0)*1000.0
Else
    DeltaXF=(ABS(CellBoundary2-CellBoundary3)/2.0)*1000.0
    DeltaX=((ABS(CellBoundary1-CellBoundary2)/2.0)+ &
        & (ABS(CellBoundary2-CellBoundary3)/2.0))*1000.0
End If


End Subroutine DeltaXValue

!-------------------------------------------------------------



End Module Subroutines3

---------------------------------------------------------------------------------------

Module Subroutines4

Use Subroutines3
Use Subroutines6

Implicit None

Contains

!----------------------------------------------------------------------------
!--------------------Subroutine SkyShine-------------------------------------
!----------------------------------------------------------------------------

Subroutine SkyShine(TAB, nofdpoints, AircraftNonPart, AircraftDose)
```

```
Integer :: i     !Counters
Integer, Intent(IN) :: nofdpoints  ! Number of Data Points used
Real(8), Dimension(nofdpoints+1,2), Intent(IN) :: AircraftNonPart
Real(8), Intent(IN) :: TAB
Real(8), Dimension(1,6), Intent(OUT) :: AircraftDose

Real(8) :: CrossSectionalArea
Real(8) :: MassFlow
Real(8) :: Altitude
Real(8) :: Velocity, GammaTFactor   !Velocity and Gamma Transmission Factor of Aircraft
Real(8) :: CabinRadius, PV, PSL

Call Aircraft(Velocity, CabinRadius, PV, PSL, GammaTFactor, MassFlow)
Call AltCompSS(TAB, nofdpoints, Velocity, GammaTFactor, &
               & MassFlow, AircraftDose, AircraftNonPart)

End Subroutine SkyShine


End Module Subroutines4

------------------------------------------------------------------------------------------

Module Subroutines5

Use Subroutines2
Use Subroutines6

Implicit None

Contains

!------------------------------------------------------------------------------
!---------------------Subroutine CabinIngestion------------------------------
!------------------------------------------------------------------------------

Subroutine CabinIngestion(TAB, MD, nofdpoints, AircraftNonPart, AircraftDose)

Integer, Intent(IN) :: nofdpoints  ! Number of Data Points used
Real(8), Dimension(nofdpoints+1,2), Intent(IN) :: AircraftNonPart
Real(8), Intent(IN) :: TAB  !Time after Burst that the aircraft flies through the cloud
Real(8), Intent(IN) :: MD   !Mission duration in hours

Real(8), Dimension(1,6), Intent(OUT) :: AircraftDose

Real(8) :: MassFlow
Real(8) :: Altitude
Real(8) :: Velocity, GammaTFactor   !Velocity and Gamma Transmission Factor of Aircraft
Real(8) :: CabinRadius, PV, PSL

Call Aircraft(Velocity, CabinRadius, PV, PSL, GammaTFactor, MassFlow)
Call AltCompCI(TAB, MD, nofdpoints, Velocity, CabinRadius, PV, PSL, GammaTFactor, &
               & MassFlow, AircraftDose, AircraftNonPart)

End Subroutine CabinIngestion


End Module Subroutines5

------------------------------------------------------------------------------------------

Module Subroutines6

Use Subroutines3

Implicit None

Contains

!------------------------------------------------------------------
```

```
!-----------------------Subroutine AltCompSS-----------------------
!-----------------------------------------------------------------

Subroutine AltCompSS(TAB, nofdpoints, Velocity, GammaTFactor, &
                & MassFlow, AircraftDose, AircraftNonPart)

Integer, Intent(IN) :: nofdPoints
Real(8), Intent(IN) :: TAB
Real(8), Intent(IN) :: Velocity, GammaTFactor, MassFlow
Integer :: k
Real(8), Dimension(1,6), Intent(OUT) :: AircraftDose
Real(8), Dimension(nofdpoints+1,2), Intent(IN) :: AircraftNonPart
Real(8) :: MFactor
Real(8) :: DeltaX, DeltaXF  ! Delta X in the data and time in that delta cell width
                            ! DeltaXF is the final Delta X

        AirCraftDose(1,1)=AircraftNonPart(1,1)

    Do k=2, nofdpoints,1
        Call DeltaXValue(k, AircraftNonPart(k-1,1), AircraftNonPart(k,1), &
                & AircraftNonPart(k+1,1), DeltaX, DeltaXF)
        Call CalculationsSS(AirCraftDose(1,1), Velocity, GammaTFactor, &
                & DeltaX, MFactor, TAB)
        AirCraftDose(1,2)=AirCraftDose(1,2)+AircraftNonPart(k,2)*MFactor
    End DO
        Call CalculationsSS(AirCraftDose(1,1), Velocity, GammaTFactor, &
                & DeltaXF, MFactor, TAB)
        AirCraftDose(1,2)=AirCraftDose(1,2)+AircraftNonPart(k,2)*MFactor

End Subroutine AltCompSS

!-----------------------------------------------------------------
!-----------------------Subroutine AltCompCI-----------------------
!-----------------------------------------------------------------

Subroutine AltCompCI(TAB, MD, nofdpoints, Velocity, CabinRadius, PV, PSL, &
                & GammaTFactor, MassFlow, AircraftDose, AircraftNonPart)

Integer, Intent(IN) :: nofdPoints
Integer :: k    !Dummy Counter Variables
Real(8), Intent(IN) :: Velocity, GammaTFactor, MassFlow, MD
Real(8), Intent(IN) :: CabinRadius, PV, PSL
Real(8), Dimension(1,6), Intent(OUT) :: AircraftDose
Real(8), Dimension(nofdpoints+1,2), Intent(IN) :: AircraftNonPart
Real(8) :: TAB  !Initial Time
Real(8) :: MFactor  ! Multiplication Factor
Real(8) :: DeltaX, DeltaXF  ! Delta X in the data and time in that delta cell width
                            ! DeltaXF is the final Delta X

        AirCraftDose(1,1)=AircraftNonPart(1,1)

    Do k=2, nofdpoints,1
        Call DeltaXValue(k, AircraftNonPart(k-1,1), AircraftNonPart(k,1), &
                & AircraftNonPart(k+1,1), DeltaX, DeltaXF)
        Call CalculationsCI(AirCraftDose(1,1), Velocity, CabinRadius, PV, PSL, &
                & MassFlow, DeltaX, MFactor, TAB, MD)
        AirCraftDose(1,3)=AirCraftDose(1,3)+AircraftNonPart(k,2)*MFactor
    End DO
        Call CalculationsCI(AirCraftDose(1,1), Velocity, CabinRadius, PV, PSL, &
                & MassFlow, DeltaX, MFactor, TAB, MD)
        AirCraftDose(1,3)=AirCraftDose(1,3)+AircraftNonPart(k,2)*MFactor

End Subroutine AltCompCI

!-----------------------------------------------------------------
!-----------------------------------------------------------------
!-----------------------------------------------------------------

End Module Subroutines6

------------------------------------------------------------------------------
```

```
Module Subroutines7

Implicit None

Contains

!-------------------------------------------------------------------------------
!------------------Subroutine FinalPrint----------------------------------------
!-------------------------------------------------------------------------------
Subroutine FinalPrint(AircraftDose, FileName, TAB)

Real(8), Dimension(1,6), Intent(IN) :: AircraftDose
Real(8), Intent(IN) :: TAB
Character(Len=15), Intent(IN) :: FileName

Open (unit=10, status="unknown", file=FileName)

Write(10,101) "Aircraft Dose"
Write(10,*)

Write(10,102) TAB, "hour"
Write(10,*)
Write(10,101)"Altitude   Sky Shine Dose     Cabin Ingestion Dose   Filtered CI Dose   &
                &Total Un-Filtered Dose   Total Filtered Dose"
Write(10,101)"-------------------------------------------------------------------&
                &-----------------------------------------"
Write(10,105) AircraftDose(1,1), " ", AircraftDose(1,2), " ", AircraftDose(1,3), " ", &
                & AircraftDose(1,4), " ", AircraftDose(1,5), " ", AircraftDose(1,6)
Write(10,*)

101 Format(A)
102 Format(F3.0,A5)
105 Format(F6.0, A1, F14.10, A3, F14.10, A8, F14.10, A5, F14.10, A11, &
      & F14.10)
End Subroutine FinalPrint


End Module Subroutines7

-------------------------------------------------------------------------------------

Module Subroutines8

Use Subroutines3

Implicit None

Contains

!-------------------------------------------------------------------
!----------------------Subroutine FiltAltCompCI-------------------
!-------------------------------------------------------------------

Subroutine FiltAltCompCI(i, nofdpoints, Velocity, CabinRadius, PV, PSL, &
                &GammaTFactor, MassFlow, AircraftDose, AircraftPartGrps, TAB, MD)
Integer, Intent(IN) :: i, nofdPoints
Integer :: k    !Dummy Counter Variables
Real(8), Intent(IN) :: Velocity, GammaTFactor, MassFlow, MD
Real(8), Intent(IN) :: CabinRadius, PV, PSL
Real(8), Dimension(1,6), Intent(OUT) :: AircraftDose
Real(8), Dimension(nofdpoints+1,10), Intent(IN) :: AircraftPartGrps
Real(8) :: TAB  !Initial Time
Real(8) :: MFactor  ! Multiplication Factor
Real(8) :: DeltaX, DeltaXF  ! Delta X in the data and time in that delta cell width
                            ! DeltaXF is the final Delta X

        AirCraftDose(1,1)=AircraftPartGrps(1,1)

    Do k=2, nofdpoints,1
```

```
        Call DeltaXValue(k, AircraftPartGrps(k-1,i), AircraftPartGrps(k,i), &
                & AircraftPartGrps(k+1,i), DeltaX, DeltaXF)
        Call CalculationsFCI(i, AirCraftDose(1,1), Velocity, CabinRadius, PV, PSL, &
                & MassFlow, DeltaX, MFactor, TAB, MD)
        AirCraftDose(1,4)=AirCraftDose(1,4)+AircraftPartGrps(k,i+5)*MFactor
    End DO
        Call CalculationsFCI(i, AirCraftDose(1,1), Velocity, CabinRadius, PV, PSL, &
                & MassFlow, DeltaX, MFactor, TAB, MD)
        AirCraftDose(1,4)=AirCraftDose(1,4)+AircraftPartGrps(k,i+5)*MFactor

End Subroutine FiltAltCompCI

!--------------------------------------------------------------------
!--------------------------------------------------------------------
!--------------------------------------------------------------------

End Module Subroutines8

------------------------------------------------------------------------------------------

Module Subroutines9

Use Subroutines2
Use Subroutines8

Implicit None

Contains

!-------------------------------------------------------------------------------
!--------------------Subroutine FiltCabinIngestion-------------------------------
!-------------------------------------------------------------------------------

Subroutine FiltCabinIngestion(TAB, MD, nofdpoints, AircraftPartGrps, AircraftDose)

Integer :: i    !Counters
Integer, Intent(IN) :: nofdpoints  ! Number of Data Points used
Real(8), Dimension(nofdpoints+1,10), Intent(IN) :: AircraftPartGrps
Real(8), Intent(IN) :: TAB  !Time after burst
Real(8), Intent(IN) :: MD   !Mission duration in hours

Real(8), Dimension(1,6), Intent(OUT) :: AircraftDose

Real(8) :: CrossSectionalArea
Real(8) :: MassFlow
Real(8) :: Altitude
Real(8) :: Velocity, GammaTFactor   !Velocity and Gamma Transmission Factor of Aircraft
Real(8) :: CabinRadius, PV, PSL
    Do i=1,5,1  !Do Loop to run through the 5 groups in each time

        Call Aircraft(Velocity, CabinRadius, PV, PSL, GammaTFactor, MassFlow)
        Call FiltAltCompCI(i, nofdpoints, Velocity, CabinRadius, PV, PSL, &
                &GammaTFactor, MassFlow, AircraftDose, AircraftPartGrps, TAB, MD)

    End do


End Subroutine FiltCabinIngestion


End Module Subroutines9

---------------------------------------------------------------------------------------

Module Subroutines10

Implicit None

Contains
```

```
!----------------------------------------------------------------------------
!--------------------Subroutine AddingDose---------------------------------
!----------------------------------------------------------------------------

Subroutine AddingDose(AircraftDose)

Real(8), Dimension(1,6), Intent(INOUT) :: AircraftDose

    AircraftDose(1,5)=AircraftDose(1,2)+AircraftDose(1,3)
    AircraftDose(1,6)=AircraftDose(1,2)+AircraftDose(1,4)

End Subroutine AddingDose

!----------------------------------------------------------------------------
!----------------------------------------------------------------------------
!----------------------------------------------------------------------------

End Module Subroutines10

-------------------------------------------------------------------------------------------

Module Subroutines11

Implicit None

Contains


!------------------------------------------------------------
!-----------------Simpson's Double Integral-----------------
!-----------------Burden & Faires, Numerical Analysis 6th ed-
!-----------------Algorithm 4.4-----------------------------
!-----------------Used for Cabin Ingestion integral----------
!------------------------------------------------------------

Subroutine SimpsonsDI(Radius, PSL, Mutrho, Density, K)

Real(8), Intent(IN) :: Radius, PSL  !Radius and PseudoLength
Real(8), Intent(IN) :: Mutrho   !Mass Attenuation Coefficient
Real(8), Intent(IN) :: Density
Real(8) :: Constant
Real(8) :: a, b, c, d   !Limits of Integration
Integer :: m, n !Subintervals for numeric integration
Real(8) :: h, J1, J2, J3, K1, K2, K3, Q, L  !Constants used in Simpsons
Integer :: i, j !For do loops
Real(8) :: x, HX, y, K
Constant=mutrho*Density
a=0.0
c=0.0
b=PSL/2.0
d=Radius

m=Int(2.0*d)
    If (mThen
        m=5
    End IF
n=Int(8.0*b)
    If (nThen
        n=10
    End IF
h=(b-a)/(2*n)
J1=0
J2=0
J3=0

Do i=0,(2*n),1
    x=a+i*h
    HX=(d-c)/(2*m)
    If (x==0 .AND. c==0) Then
        K1=0
    Else
```

```
        K1=(FNXY(Constant, x, c)+FNXY(Constant, x, d))
    End IF
    K2=0
    K3=0

    Do j=1,(2*m-1),1
        y=c+j*HX
        Q=FNXY(Constant, x, y)
        If (J==(2*(J/2))) Then
            K2=K2+Q
        Else
            K3=K3+Q
        End IF
    End DO

    L=(K1+2.0*K2+4.0*K3)*HX/3.0

    If (i==0 .OR. i==(2*n)) Then
        J1=J1+L
    Else IF (i==(2*(i/2))) Then
        J2=J2+L
    Else
        J3=J3+L
    End IF

End DO

K=h*(J1+2.0*J2+4.0*J3)/3.0

End Subroutine SimpsonsDI

!---------------------------------------------------------------
!--------------------------Function for integrals--------------
!---------------------------------------------------------------
Real Function FNXY(Constant, r, z)

Implicit None

Real(8), Intent(IN) :: Constant, r, z

FNXY=(Exp(-Constant*(r**2.0+z**2.0)**(1.0/2.0))*r)/((r**2.0+z**2.0))
! Since only half of the interval is used(0 to PSL/2), this function is multiplied
! by 2 and this is why the 2 disappears in the denominator
End Function FNXY

End Module Subroutines11
```

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Vita

Lt. Fred E. Garcia II was born on in Denver, CO to and

He graduated from high school in 1993 at Skyview High School in Billings, MT and attended college, on a 4 year Air Force ROTC scholarship, at Embry-Riddle Aeronautical University in Daytona Beach, FL. There he earned his Bachelor of Science degree in Engineering Physics with a minor in Mathematics. After college, the Air Force sent him to Wright-Patterson AFB, OH for his first military assignment in Logistics Acquisition Management. In this assignment, he was part of a source selection team in the LANTIRN program office to determine the next targeting/navigation pod for the Air Force Reserve and Air National Guard, the Precision Attack Targeting System. He was a logistics analyst and aided in source selection management. After a year in acquisitions, Lt. Garcia was chosen to be a part of a countermeasure team at the Countermeasure Hands On Program (CHOP) at Kirtland AFB, NM. There, he was the lead mechanical engineer on the team tasked to build a complete re-entry vehicle based on third world technology. He designed the complete mechanical aspects of the re-entry vehicle and started fabrication before he headed back to Wright-Patterson to start a Masters degree in Nuclear Engineering. Lt. Garcia's next assignment is going to be at Offutt AFB, NE with USSTRATCOM/J534.

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14. ABSTRACT

Total radioactive doses to aircrew members have been calculated in the past using different methods. The methodologies include smearing models, disk-tosser codes, and puff models. This study uses output data from the Hazard Prediction and Assessment Capability (HPAC) code as input into a FORTRAN program written by the author to calculate total dose to aircrew members through sky-shine and cabin ingestion.

A description of the input parameters and new project setup in the Nuclear Weapon (NWPN) module within HPAC is given. The various aspects of controlling the project and plotting the data are also described. This information is presented essentially as a user's guide to NWPN that is focused toward the baseline case of this study.

The basic theory behind nuclear bursts including discussion about particle distribution is given. The particle distributions that are used in HPAC are plotted using different lognormal parameters in order to find a best fit for the data. This information is included in order to better understand the science behind HPAC's particle size distributions.

Theory of sky-shine and cabin ingestion dose is presented and a methodology to calculate total dose to aircrew members based on HPAC output data is given. The approach taken in this study is to use FORTRAN, oriented toward operational use, to extract this total dose for various altitudes, times after burst, and for different mission durations.

15. SUBJECT TERMS

HPAC, NWPN, radioactive doses to aircrew, smearing model, disk-tosser, puff model, FORTRAN, sky-shine, cabin ingestion, particle distribution, log normal, cumulative log normal, total dose, rem.

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